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# ENDEAVOUR

The British quarterly scientific journal ENDEAVOUR was first published, by Imperial Chemical Industries Limited, in January 1942. Its purpose is to provide scientists, especially those overseas, with news of the progress of the sciences. While emphasis is laid upon British work, narrow insularity is avoided by publishing a number of articles from overseas contributors and by impartial reference to the world's scientific literature. To make the journal truly international in character it is published in five separate editions—English, French, German, Italian, and Spanish.

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*The drawing on the cover is of the bark* Endeavour, *which, commanded by Captain James Cook and carrying a number of scientific workers, was sent out by the British Admiralty in* 1768 *to chart the South Pacific Ocean and observe the transit of Venus*

# ENDEAVOUR

A quarterly review designed to record the progress of the sciences in the service of mankind

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# The International Geophysical Year

Geophysics in its many different aspects depends more than most branches of science upon international co-operation for its advancement. Two great international enterprises, the first and second International Polar Years, contributed materially to our knowledge and understanding of several branches of geophysics, in particular to those concerned with the Earth's magnetism, the aurora, and meteorology. The first of the Polar Years was in 1882–3; the second in 1932–3. In both these years a number of special stations were established in the polar regions, where the disturbances in the Earth's magnetic field are greatest, the aurora is most frequently to be seen, and the two most intense storm centres of the world are found.

At the time of the second Polar Year ionospheric investigations were in their infancy, but some important observations were made, though the methods used now seem crude. As various new techniques and methods of observation have been developed since 1933, and as many of the problems in geophysics depend for their solution upon observations being made in many different parts of the world, a widespread feeling developed that a third year, devoted to a concerted attack on these problems, would be of great value.

A proposal to this effect was brought in 1950 and 1951 before the three international scientific unions chiefly concerned and endorsed by them. The International Council of Scientific Unions approved of the proposal and widened its scope to include observations in all latitudes, so that the enterprise is now designated the International Geophysical Year. An international committee was appointed to supervise the plans, and national committees have been formed by the participating countries, which now number thirty-six. It is gratifying that the Soviet Union, though not a member nation of the International Council of Scientific Unions, has accepted the invitation to participate. The World Meteorological Organization has also agreed to participate.

The special Committee for the International Geophysical Year (known as C.S.A.G.I., *Comité Spécial de l'Année Géophysique Internationale*) has decided that the 'year' shall extend from July 1957 to December 1958, and will thus follow the second Polar Year after an interval of twenty-five years. The epoch is important. The second Polar Year came at a time of minimum sunspot activity, when the Sun was in a relatively quiescent state. As the Sun passed through a minimum of activity in 1954 it will by 1957–8 be near maximum activity.

The close association between solar activity and terrestrial phenomena, such as geomagnetic disturbances, the aurora, ionospheric storms, and the vagaries of radio propagation, is well established. But there is much that is still obscure about the physical processes involved. Detailed observations of the Sun and of the variable solar features by visual, photographic, spectrographic, and radio methods will therefore form an essential part of the programme. Arrangements are being made to ensure that the Sun will be kept as nearly as possible under continuous observation from stations well distributed in longitude. The observations will include observations of the corona at high-altitude stations; measurements of the general magnetic field of the Sun and of the localized fields associated with sunspots and other disturbed areas; cinematograph patrol of solar features and chromospheric disturbances; and observations of solar emissions at radio wavelengths.

The scope of the geophysical observations to be undertaken will be much wider and much more comprehensive than during the two Polar Years. The subjects studied will include meteorology, geomagnetism, the aurora, the airglow, ionospheric physics, cosmic rays, longitude and latitude determination, glaciology, and oceanography.

The permanent stations which make observations in these subjects will naturally participate in the programme, and for the most part their observations will be extended. But these stations are not adequately distributed, and accordingly many special stations will be established at strategic points to fill in the more important gaps between the permanent ones.

Three meridian chains of stations have been planned. The first of these extends along approximately the meridian of 80° W from the Arctic, through North America, along the west coast of South America, and into the Antarctic. The second is along the meridian of 10° E, through western Europe, Tunisia, the Sahara, and the west coast of Africa to the Antarctic. The third is along the meridian of 140° E, through Soviet territory, Japan, New Guinea, and Australia. These meridian chains are of special importance for the investigation of the general circulation of the atmosphere, which forms the most important item in the programme of meteorological investigation,

though they will also contribute to other parts of the general programme.

Special attention is being given to the Antarctic, the Arctic, and the equatorial regions. The first is a region of great interest. Its influence on global weather and on atmospheric and oceanographic dynamics needs to be investigated. Little is at present known of the aurora australis and whether its characteristics differ from those of the aurora borealis. The course of the southern zone of maximum auroral frequency has not been adequately investigated. The characteristics of the ionosphere during the prolonged absence of sunlight will be determined. Both polar regions are of special importance for geomagnetic studies. Plans have already been made for eleven stations on the Antarctic continent or below the Antarctic circle and for ten stations on neighbouring islands; it is hoped that arrangements will be made for a further five stations on the continent and three on neighbouring islands. One station will be set up at or near the South Pole. In the Arctic the zone of maximum auroral frequency is well placed for observation, and the co-operation of Soviet scientists in observations in this region is particularly welcome. Meteorology, the aurora and airglow, geomagnetism, and the ionosphere will receive particular attention. It is hoped to establish several temporary stations in Greenland.

The equatorial region is of importance in geomagnetic, ionospheric, and cosmic ray studies. The equatorial jet-current system in the upper atmosphere, whose existence seems to be required from the observed magnetic variations at stations near the geomagnetic equator, will be investigated. Observations of ionospheric critical frequencies and of cosmic rays in the equatorial region, are required to determine their dependence upon geomagnetic latitude.

Balloons will be widely used to obtain information about the density, pressure, and temperature of the atmosphere, of the wind velocities, and of cosmic ray intensities up to heights of about 20 miles. Aircraft will be used for special soundings of the ionosphere. Rockets capable of reaching heights up to 125 miles, and smaller rockets, launched from balloons or aircraft, capable of reaching heights up to 50 miles, will be equipped with a variety of recording or telemetering equipment. By such means the atmospheric data can be extended to greater heights; the composition of the atmosphere at different heights can be determined; the electrical current systems in the atmosphere, which cause some of the observed variations in the Earth's magnetic field, can be investigated; and the spectrum of the Sun in the far ultraviolet region can be photographed.

A world-wide programme of determinations of longitudes and latitudes has been included in the programme. Seasonal changes in the angular momentum carried by the winds are compensated by corresponding changes in the angular momentum of the Earth, causing a small seasonal variation in its rate of rotation. Seasonal changes in pressure, entailing the displacement of large masses of air, tilt the Earth's axis slightly and produce an annual variation in observed latitudes. These effects will be investigated in conjunction with meteorological data.

The Moon and stars will be photographed by cameras of special design, attached to telescopes at astronomical observatories, for the investigation of the changes in the Earth's rotation and for triangulating the whole Earth. It has not been possible hitherto to make accurate maps showing the continents in their proper relation to each other because the normal methods of geodetic triangulation cannot be extended across the oceans.

In addition to the normal day-by-day observations, two days in each month, to be known as Regular World Days, have been selected for concentrated observations at all stations. One of these days will be the day of new moon and the other will be at or near quarter-moon. Some additional World Days have been selected for special observations because they will be days of unusual meteoric activity or days on which an eclipse of the Sun will occur. For the investigation of atmospheric movements some periods longer than a day are desirable. During each quarter an interval of ten consecutive days, a World Meteorological Interval, has been selected for intensive meteorological observation.

Intensive observations are desirable during times of outstanding solar activity. Such times cannot be predicted, with any certainty, long in advance. A plan has therefore been formulated for an alert to be transmitted through communication networks whenever unusual solar activity seems likely to occur, as a warning that a Special World Interval is likely to be declared within the next four to six days.

The International Geophysical Year will form the greatest scheme of international co-operation in science ever planned. That it will add greatly to the knowledge and understanding of geophysical phenomena and that it will prove of great benefit to mankind is certain.

# High-energy particle accelerators

SIR JOHN COCKCROFT and T. G. PICKAVANCE

The big machines for the acceleration of charged particles are among the most complex and costly of modern scientific devices, but there is still little general understanding of their principles and applications. This authoritative article describes the main types now in use, with some details of individual machines, and gives examples of the kinds of research for which they are needed. Of particular interest is their use for the artificial production of some of the new particles which have been identified in cosmic rays.

Only forty years ago Rutherford and his collaborators first demonstrated the nuclear model of the atom by studies of the scattering of α-particles, derived from naturally radioactive sources, by the Coulomb field of atomic nuclei. Since those days, the electrical acceleration of charged particles in large machines has contributed much to the rapid development of nuclear physics. In the early 1930's the first accelerators—the high-tension generator of Cockcroft and Walton and the cyclotron of Lawrence—accelerated protons by a few hundred kilovolts. The biggest accelerator today, at Berkeley, California, produces protons of $6 \times 10^9$ electron volts, or 6 (U.S.) billion electron volts—hence its name 'Bevatron'. (In Europe it is now the accepted practice to use GeV for $10^9$ electron volts, in place of the American BeV.) Two machines are now planned for producing protons with energies of 20–30 GeV. One of these machines is to be built in the newly constituted *Organisation Européenne pour la Recherche Nucléaire* (CERN) at Geneva. The United Kingdom is one of the twelve member states of CERN; the others are Belgium, Denmark, France, the Federal German Republic, Greece, Holland, Italy, Norway, Sweden, Switzerland, and Yugoslavia. The other machine will be built at the Brookhaven National Laboratory in the United States.

The main tasks for both existing and future machines are concerned ultimately with attempts to obtain an understanding of nuclear forces. Typical lines of attack are the study, over a wide range of bombarding energies, of the scattering of protons by protons and of neutrons by protons, and, in the larger of the existing machines, studies of the production of π-mesons and their interaction with other particles. π-mesons, which are observed in positive, negative, and uncharged forms, have masses about 280 times the mass of the electron and are unstable; their mean lives are of the order of $10^{-8}$ second (positive and negative forms) and $10^{-15}$ second (uncharged form). They are thought to play a very important part in the forces which hold neutrons and protons together in nuclei. Although the charged varieties of π-mesons were discovered in studies of cosmic rays by C. F. Powell and his collaborators at Bristol, they are produced only very weakly by cosmic rays. They can be obtained in comparative abundance when nuclei are bombarded by intense beams of particles possessing kinetic energy of some hundreds of MeV. At still higher energies other, and more massive, unstable particles, including the V-particles discovered in cosmic rays by P. M. S. Blackett's school in Manchester, are produced artificially. Many examples of these have already been observed, using the 2·8 GeV Cosmotron at the Brookhaven National Laboratory. The significance of these strange particles, which have been discovered in considerable variety in cosmic rays, is still obscure, and it is necessary to learn much more about them. The very large machines will be needed for these studies; it seems reasonable to expect considerably greater yields, and greater variety, of these particles as the available bombarding energy is increased. The 20–30 GeV machines now being planned will also produce enough energy to create pairs of particles of nucleonic mass in collisions between two nucleons, if such processes occur, as it is believed they should, with sufficient spare energy to ensure good yield and high velocity of the artificially produced particles. Studies of the properties of negative protons and of the circumstances in which they may be produced would be of very great theoretical importance.

Low-energy machines are not necessarily made obsolete by the development of bigger ones, and there is much interest in all energy ranges, including the 1 MeV region, first reached long ago. It is always necessary to examine rare processes and to strive for greater precision in experiment,

and such work requires beams of high intensity. Machines designed to give great energies are, however, usually not the best sources of particles of lower energy, since it is necessary to sacrifice intensity, and often flexibility, in order to obtain high energies at acceptable cost. The gaps in our knowledge of nuclear phenomena are still enormous, and experiments with particles of all obtainable energies are still needed to help to fill them.

Both electrons and heavy particles, usually protons, are used in high-energy experiments. In some types of machines it is electron acceleration that is the more easily or more cheaply obtainable, but the two kinds of particles cannot be accelerated in the same machine. Protons, however, are, in general, more powerful tools in nuclear physics, and accordingly more effort has been put into the making of proton machines than of electron machines. However, there are certain electromagnetic phenomena which can be investigated only with the help of electron beams.

## General Features of High-energy Accelerators

All accelerators of high-energy particles use stepwise acceleration by radio-frequency electric fields, with the exception of the betatron; this machine has been used to accelerate electrons up to about 300 MeV by means of the electric field associated with a changing magnetic field. The central problem dominating the design of big machines is that of particle stability; this problem has two aspects. First, the particles repeatedly encounter electric fields, applied across gaps by a radio-frequency source, and it is necessary to ensure that a useful proportion of the particles continue to arrive at the gaps at times in the radio-frequency cycle when further acceleration can occur. Secondly, it is essential to adopt some means of focusing the particles into a beam, so that useful numbers pass through the gaps instead of striking solid parts of the accelerating system. The phase of the particles with respect to the radio-frequency field is influenced by the properties of the particle injection system, unavoidable constructional and similar errors, and amplitude and frequency errors in the radio-frequency field. Unwanted changes in the direction of motion of the particles are caused by injection conditions, constructional errors, and scattering by residual gas in the vacuum chamber. The relative importance of these different factors varies with the type of accelerator, but in all very big machines, where many individual accelerations occur and the total path-length of the particles is long, it is necessary to provide positive 'focusing' of both phase and direction for a proportion of the injected particles large enough to be useful. There will be stable oscillations of the phase, and therefore of particle energy and position, about certain equilibrium or synchronous values. Similarly there will be oscillations of particle position associated with the spatial focusing forces. These oscillations have a great influence on the design and performance of the machines.

The machines fall into two general groups, namely linear accelerators and closed-orbit accelerators. In linear accelerators, many gaps and many radio-frequency power sources (or, in a small machine, a single source of high power) are used to accelerate particles in a straight line. In the closed-orbit accelerators, a magnetic guide-field is used so that the same gap, or series of gaps, may be used repeatedly, with few radio-frequency sources of relatively low power. For protons or other heavy particles the closed-orbit machines (the synchrocyclotron and the proton synchrotron) are well ahead in the race for the highest energies. For electrons the linear accelerator may possibly be the machine of the future, even for the highest energies; at lower energies, from say five MeV to a few hundred MeV, its superiority over existing types of closed-orbit machines appears to be already evident.

The reason for this state of affairs is that there are difficulties inherent in the linear accelerator which are important only when protons are to be accelerated, and that there is a difficulty in the closed-orbit machine which is important only when electrons are to be accelerated. The region of phase-stable acceleration in a linear accelerator is one in which strong directional defocusing occurs. At extreme relativistic velocities, which occur at quite low electron energies, however, the motion caused by the defocusing electric forces virtually disappears, and trouble may be readily avoided after the first few MeV (in practice the first few metres) of acceleration in a linear machine. Moreover, linear accelerators of electrons may be operated at short wavelengths, usually about 10 cm, and the accelerator proper consists of a corrugated waveguide of small diameter. Compact microwave power sources, each giving several megawatts in short pulses, have become available by the development of klystron valves at Stanford University. On the other hand, slow particles, e.g. protons of a few hundred MeV or less, may be

accelerated efficiently only by the use of longer wavelengths, of the order of 1 metre, and with conventional systems a large and relatively costly waveguide has to be used. Compact, efficient, high-power sources for these wavelengths have not yet been developed, and this circumstance, together with the focusing difficulty and the great success of closed-orbit machines, explains why the linear accelerator of protons has undergone relatively little development so far.

The difficulty with closed-orbit electron machines, electron synchrotrons, is that energy is radiated by the circulating electrons, and this loss of energy has to be made good by the radio-frequency accelerating system. The effect is very small with the heavier protons, even in the biggest machines now planned, but it becomes serious with electrons at energies of a few GeV. In the linear accelerator radiation loss is completely negligible, even with electrons.

## Economic Factors

The larger accelerators are exceedingly costly, and economic considerations play a very large part in determining the types of accelerator which can be used for the highest energies. For example, the Brookhaven Cosmotron, which produces 2·8 GeV protons (to be increased to 3·0 GeV), is reported to have cost $7 000 000, and the 20–30 GeV machine now being designed at Brookhaven is expected to cost $20 000 000. The magnet and its power supplies accounted for one-quarter of the cost of the Cosmotron. The particle energy in a closed-orbit machine is determined by the product of orbit radius and magnetic field strength, but the magnetic field is restricted, by saturation effects in the iron, to 20 000 gauss or less. Consequently particle energy can be increased only by increasing the orbit radius.

The synchrocyclotron has proved to be one of the most reliable and powerful accelerators ever developed, but its use is precluded for the highest energies because the magnet cost rises very rapidly with the energy required. The magnet of a 600 MeV synchrocyclotron to be built by CERN in Geneva will contain 2500 tons of steel and will cost roughly £500 000; it will have a final orbit radius of about 225 cm. The proton synchrotron, on the other hand, accelerates particles in a magnetic field which increases with time in such a way that the orbit radius remains constant. The magnet of this machine has therefore to produce a strong field only in an annular volume, with a consequent saving of steel for a given orbit radius. The Brookhaven Cosmotron is a machine of this type; its magnet contains about 2000 tons of steel for an orbit radius of about 9 metres, so that protons having four or five times the energy of those obtainable from the CERN synchrocyclotron may be accelerated, using rather less steel. However, the proton synchrotron poses many problems, concerned with maintaining particle stability, which are absent from the synchrocyclotron and, moreover, produces, with present techniques, a beam of much smaller intensity. At the highest energies now being aimed at, 20–30 GeV, even the proton synchrotron in its present form would be much too expensive, and attempts are being made to exploit a principle, recently discovered at Brookhaven and independently by N. Christophilos, a Greek scientist, which makes it possible to use a magnet gap of much smaller volume and thus to reduce the weight and cost of the magnet still further.

## Some Features of Particular Types of Accelerators

### linear accelerators

We are here concerned only with high-energy accelerators, and only one linear electron accelerator in this category has yet been built. This is at Stanford University, and consists of a sectioned, corrugated waveguide having a total length of 60 metres and operating at a wavelength of 10 cm. Power is supplied by twenty-one special klystrons developed at Stanford, each giving more than 10 megawatts of power in pulses of about a microsecond duration. An energy of about 600 MeV has been attained, and it is hoped to increase this to some extent in the future. Already important results on the scattering of high-energy electrons by atomic nuclei have been obtained with the help of this machine.

The biggest linear accelerator for protons now in operation is a 32 MeV machine constructed some years ago at the University of California, but a 60 MeV machine is nearly complete at the University of Minnesota. At the Atomic Energy Research Establishment, Harwell, and at Metropolitan-Vickers Electrical Company Limited, a design study has been made for a much larger machine, for protons of 600 MeV. The absence of beam-extraction problems means that, compared with a synchrocyclotron accelerating the same proton current, more intense beams of particles can be made available for experiments. This, together with the possibility of subsequent extension to higher energies, makes the high-energy

linear accelerator for protons an attractive machine, particularly for work in π-meson physics, if it can be constructed at reasonable cost. Recent improvements in the extracted beam from the synchrocyclotron, referred to later, have, however, diminished its advantages. A proton linear accelerator for 600 MeV would be about 300 metres in length and would require 100–150 megawatts of radio-frequency power during the pulses. In the Harwell design, most of this power would have to be provided at a frequency of 400 Mc/s, and a valve development programme would be an essential part of the project. The pulse duration would be 200 microseconds, and the pulses would occur 50 times per second, so that the mean radio-frequency power required would be 1–1·5 megawatts.

### THE SYNCHROCYCLOTRON

Here the particles travel in concentric closed orbits in a steady magnetic field, and are accelerated by a radio-frequency electric field. They start with very small velocity, and therefore with very small orbit radius, and the orbit radius increases as acceleration proceeds. The orbital period increases slightly with increasing energy. Some of this increase is accounted for by the fact that the magnetic field is made to decrease slightly as the radius increases, in order to provide the necessary focusing forces, and the remainder by the relativistic increase of mass of the particles with increasing velocity. The frequency of the accelerating field is reduced slowly, during acceleration, to an extent which compensates for the increasing orbital period, so that some of the particles may remain in step with the accelerating field. It can easily be shown that, over a broad range of operating conditions, phase stability of an appreciable fraction of the injected particles can be achieved in this way. Moreover, the focusing forces produced by a slight radial decrease of the guiding magnetic field are strong enough to ensure that few particles are lost after 'trapping' into the phase-stable orbits has occurred.

This machine has been applied only to heavy particles, such as protons, and not to electrons, because electrons acquire almost the velocity of light at quite low energies, and consequently a very wide range of frequency modulation would have to be used in handling them.

There are six large synchrocyclotrons in the United States, ranging in energy from 140 to 450 MeV; one in Canada (110 MeV); one in Sweden (190 MeV); and two in Great Britain. The new Liverpool synchrocyclotron (figure 3) produces 400 MeV protons, and the Harwell machine, which has been operating since 1949, produces protons of 175 MeV (figure 4). The machine at Berkeley, California, which was the first to operate (1946), is shortly to have its maximum proton energy increased from 340 to 730 MeV. The new 600 MeV machine which is being designed for CERN at Geneva has already been mentioned.

A notable advance in synchrocyclotron technique has recently been achieved in H. W. B. Skinner's laboratory at Liverpool. A new method of beam extraction, originally proposed at Chicago some time ago but developed theoretically and experimentally by K. J. Le Couteur, A. V. Crewe, and others at Liverpool, has been applied to the new 400 MeV synchrocyclotron. Already 3 per cent of the internal beam current has been extracted; this is an improvement, by a factor of at least 1000, over previous methods, and will enormously extend the usefulness of synchrocyclotrons in high-energy research.

### THE ELECTRON SYNCHROTRON

Here the guiding magnetic field is increased with time, during acceleration by the radio-frequency field, in such a way that the orbit radius remains constant. If the electrons are injected at an energy of a few MeV, or are accelerated by betatron operation in the early stages, their velocity will be essentially constant thereafter and the frequency of the radio-frequency field may also remain constant. The magnetic field need be applied only over an annular volume, but the magnet yoke has to be laminated in order to avoid eddy-current effects as the field is varied.

In experiments with electron synchrotrons it is customary to use the *Bremsstrahlung*, the continuous spectrum of electromagnetic radiation produced when electrons are absorbed in an internal target. This high-energy electromagnetic radiation provides a powerful experimental tool. Although some success has been achieved in attempts to extract the electron beam, the technical difficulties are considerable.

There are several large electron synchrotrons in the United States, producing about 300–350 MeV, and a 350 MeV machine was recently completed in Glasgow (figure 5). A machine of this type at the California Institute of Technology produces electrons of nearly 1 GeV, and a new 5–6 GeV machine has been proposed as a joint venture by the Massachusetts Institute of Technology and Harvard University.

THE PROTON SYNCHROTRON

This type of machine is of special interest, since with present techniques it gives the highest artificially produced particle energies. As with the electron synchrotron, the magnet is laminated, has an annular gap, and produces a field increasing with time during acceleration. However, the proton velocity increases appreciably as the energy increases, until the velocity of light is approached at energies of several GeV. It is necessary, therefore, to increase the frequency of the radio-frequency field during acceleration in order to maintain constant orbit radius, and the correlation ('tracking') of the frequency variation with the magnetic field variation has to be very accurately carried out. This introduces considerable complication that is not present in the other machines. Moreover, it is not economically possible to recycle the magnetic field very rapidly in a large magnet, and the particles are accelerated in bursts occurring a few times per minute. In contrast, the frequency variation in the synchrocyclotron can be made quite rapidly, and in that machine it is common practice to use about 100 bursts per second. As a result of these various factors the mean intensity of the particle beam of a proton synchrotron is, with present techniques, at the most one-thousandth of that of a synchrocyclotron.

M. L. E. Oliphant, when he was at Birmingham, was the first to propose the machine which later became known as the proton synchrotron. The Birmingham machine (figure 6) has been operating for some time at an energy of 1 GeV. Figure 7 is a photograph of the 2·8–3·0 GeV Cosmotron at Brookhaven. Protons are first accelerated to about 4 MeV in an electrostatic generator, and are then injected into the gap of the large magnet, where they are accelerated further during the course of about $3 \times 10^6$ circulations, made in about one second. The distance travelled in this process is about $1{\cdot}6 \times 10^5$ km. The magnet is energized in pulses by a 21 000 kVA alternator carrying a 45-ton flywheel on the driving shaft. In this way the flywheel gives up a fraction of its kinetic energy to the electrical system during the pulse, after which it is accelerated again, in readiness for the next pulse, by a relatively small motor (1750 H.P.). About 75 per cent of the stored energy in the magnet (about $10^7$ joules) is returned to the flywheel, with the help of gas-discharge switches in the alternator circuit, during the interval between pulses. The same system, with variations in detail, is used in all existing proton synchrotrons. The 6 GeV Bevatron at Berkeley, California, is even larger (figure 8). The magnet weighs 10 000 tons and the orbit radius is about 18 metres, and in this case the particles are injected from a 10 MeV proton linear accelerator. A new machine for 15 GeV, using an air-cored magnet, is being built in Australia under the direction of Oliphant.

The focusing forces, which are necessary in order to return straying particles to the correct orbits, are associated with stable oscillations of the particles about the correct orbits. As we have seen, it is an important economic consideration in the proton synchrotron to use as small a magnet gap as possible, but the space required by these oscillations, and by perturbations due to unavoidable constructional and timing errors, sets a limit to it. If the frequency of the oscillations could be increased, it is clear that the amplitude resulting from a given angular displacement of a particle would be correspondingly reduced. With the normal (constant gradient) method of focusing in a closed-orbit accelerator, particle stability requires that $1 > n > 0$ where $n$ is a parameter which describes the magnetic field distribution and is defined by

$$n = -(r/B)\,\partial B/\partial r,$$

where $B$ is the magnetic field intensity and $r$ is the orbit radius. For synchrotrons the value of $n$ is commonly about 0·6.

The frequencies of the oscillations associated with the focusing forces (the 'betatron oscillations') are:

$$f_r = (1-n)^{\frac{1}{2}} f_0 \quad \text{(radial)},$$
$$f_v = n^{\frac{1}{2}} f_0 \quad \text{(axial)}$$

where $f_0$ is the orbital frequency. There is clearly little scope for changing the frequencies, and an increase in one will involve a decrease in the other.

M. S. Livingston, E. D. Courant, and H. S. Snyder at Brookhaven, and independently Christophilos in Greece, showed in 1952 that a net focusing effect may be achieved in a suitably arranged system which is alternately focusing and defocusing along the path of the moving particles. With $n$ numerically $>> 1$, but with $n$ alternately positive (radially defocusing, axially focusing) and negative (radially focusing, axially defocusing), a synchrotron may be designed with much stronger focusing forces for displacement in both directions, i.e. with higher frequencies of stable oscillations, than those of the conventional synchrotron.

The frequencies of the betatron oscillations are now greater than the orbital frequency, and, as was first pointed out by J. D. Lawson at Harwell,

the particle motion in an alternating gradient synchrotron is very sensitive to small misalignments of the individual focusing or defocusing sections of the guiding magnet. In particular, disastrous resonance effects occur if the number of betatron cycles per orbital revolution becomes integral or half integral, resulting in loss of the particles to the walls of the vacuum chamber. The values of $n$, i.e. the strength of focusing, have therefore been reduced below the 5000–10 000 originally contemplated, in order to leave, as it were, more operating space between the resonances. Even at the values of a few hundred for $n$ at present envisaged at CERN and Brookhaven, for the 20–30 GeV machines, a considerable reduction of magnet aperture is still possible, with a corresponding saving in capital cost. There are many other problems, mostly concerned with the maintenance of particle stability, and both groups have been actively studying these, as well as engineering design, for about two years.

The orbit radii of these machines will be about 100 metres, and the particles will have to be constrained to move through an aperture about $7 \times 12$ cm during many thousands of orbits. Very close mechanical, magnetic, and timing tolerances will have to be achieved, but the total weight of steel in the magnet can be kept down to about 4000 tons for an energy of 25 GeV. This is only twice the weight of steel in the Cosmotron, which has a vacuum-chamber aperture of $91 \times 23$ cm.

The same method of alternating gradient focusing, but with zero field along one axis, has made it possible to be reasonably confident of success in attempting to focus the beam of a proton linear accelerator without serious loss of particles.

## Some Typical Experiments with High-energy Accelerators

### Proton polarization

The discovery, at the University of Rochester in 1953, of polarization effects in the scattering of high-energy protons by nuclei, exemplified the element of the unexpected in scientific research. It had long been thought that polarization should occur in the scattering of nucleons by other single nucleons, as a result of non-central components of the nucleon-nucleon forces, and attempts were being made to obtain experimental evidence. Polarization may be detected in a 'double scattering' experiment, in which particles, scattered in a particular direction with respect to the primary beam, are passed through a second scattering device. If polarization effects are present, the beam emerging from this second device at a fixed angle with respect to the first-scattered beam will have a different intensity when scattered to the left as compared with the right. In a polarization experiment on proton-proton scattering, the bombarding particles would be protons, and ideally both scatterers would consist only of hydrogen. The use of hydrogen is inconvenient, however, and at Rochester the practice was adopted of using hydrocarbons, a subsequent experiment with pure carbon enabling the effect due to hydrogen to be distinguished. Polarization in proton-proton scattering was detected, but a considerably stronger polarization was discovered in the pure carbon. All elements which have been tried exhibit similar effects. The phenomenon has been found to be associated with the nucleus as a whole, and not with the individual nucleons, and the strongest polarization appears to occur in elastic collisions, i.e. those in which nuclear excitation or disintegration does not take place.

There has been great activity in this field during the past year, and results have been obtained at Rochester, Chicago, and Berkeley in the United States, and at Harwell in Britain. Figure 1 is a diagram of the experimental arrangement used at Harwell. Protons of maximum energy 160 MeV are allowed to strike a target $T_1$ in the vacuum chamber of the Harwell synchrocyclotron; those scattered through an angle of about 20°, and possessing an energy of 135 MeV, escape from the magnet through a magnetic shielding channel C. These first-scattered particles pass, in an evacuated tube, through a concrete shielding wall S and are collimated by slits. A second scattering takes place in the target $T_2$, and the second-scattered particles are detected in a system of counters D arranged as a 'telescope' and set at an angle $\theta$ with respect to the first-scattered beam. The primary beam, and the first- and second-scattered beams, are all arranged to be in the same plane. The detecting counters D may be rotated through 180°, about the first-scattered beam as an axis, into the position shown in dotted lines in figure 1. If there is polarization, the number of particles counted in these two positions, for a standard bombardment in each case, will be different. Elaborate checks are made, of course, to ensure that any effect observed is not attributable to errors in the alignment of the apparatus. The quantity determined is the 'asymmetry,' defined as

$$\epsilon = \frac{N_1 - N_2}{N_1 + N_2}$$

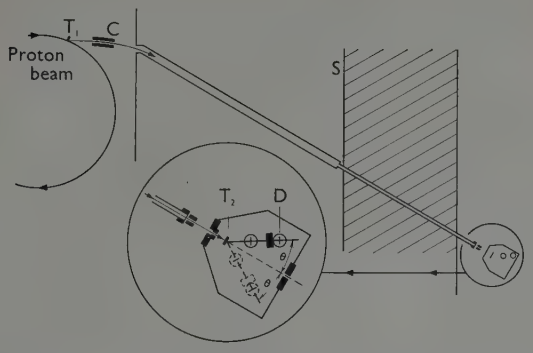


FIGURE 1 – *Plan of an experiment on the polarization of high-energy protons, using the Harwell synchrocyclotron.*

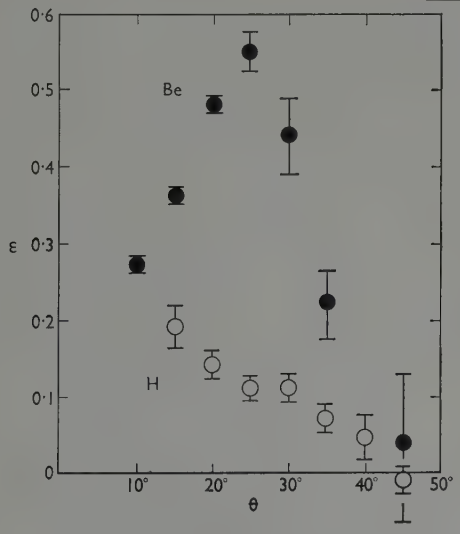


FIGURE 2 – *Variation of observed asymmetry ε with second scattering angle θ, in Harwell experiments on the polarization of high-energy protons.*

where $N_1$ is the number of particles scattered in the same direction as the first scattering (same azimuthal angle) and $N_2$ is the number of particles scattered in the opposite direction (azimuthal angle different by 180°).

The polarization at a particular angle can easily be calculated from the observed asymmetry, provided that one and the same process is known to be involved in each scattering and the two scattering angles are the same. Much of the experimental programme on this phenomenon has to be devoted to attempts to separate the different scattering processes which occur when high-energy protons strike a target. However, if a finite value of ε is obtained, then polarization is clearly taking place, and figure 2 shows the observed values of ε as a function of second-scattering angle in experiments at Harwell.

### OBSERVATION OF INDIVIDUAL PARTICLES

It is always necessary to use, in addition to counter techniques, methods of detection which display the tracks of individual particles for visual examination. These methods are very laborious when statistics comparable with those obtainable with counters are required, but are indispensable in the initial interpretation of many phenomena, particularly when 'new' particles are involved. Tracks may be made visible in cloud chambers and similar instruments, and in special photographic emulsions.

Two recent developments in the cloud chamber technique have greatly increased its effectiveness for use with accelerators. The original cloud chamber of C. T. R. Wilson produces supersaturation of a vapour-gas mixture by a controlled adiabatic expansion, and the tracks of ionizing particles are indicated by the formation of droplets on the ions. The tracks are photographed, usually by a stereoscopic camera so that the particle trajectories may be reproduced in three dimensions. Momentum measurements may be made if a magnetic field is applied during the passage of the particles through the chamber, and tracks may be observed resulting from nuclear collisions in the gas or vapour or in plates of solid material introduced into the chamber. Although this technique has been greatly developed, mainly by cosmic ray physicists, it is not very economical of the running-time of large accelerators, because the time required between expansions is greater than the normal interval between accelerator pulses. In the diffusion cloud chamber, first proposed by A. Langsdorf and developed in recent years mainly at Brookhaven, a gas may be continuously supersaturated with vapour by means of a thermal gradient on the walls of the containing vessel. This technique has been made to work very well with hydrogen, at about 20 atmospheres pressure, in vessels a few metres wide; a chamber of this kind is capable of receiving beam pulses at the full rate of about 10 per minute from a machine such as the Cosmotron. Hydrogen is, of course, a particularly important substance in studies of elementary nucleonic processes, and it is always important, when studying rare events, to be able to observe a particle traversing a great mass of material, so that the high pressure and large size of the chamber are important features. Figure 9

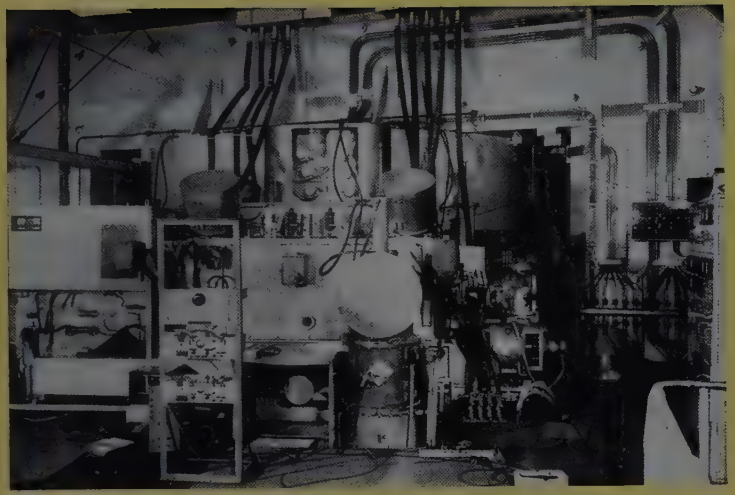

FIGURE 3 – *The 156-inch Liverpool synchrocyclotron.*

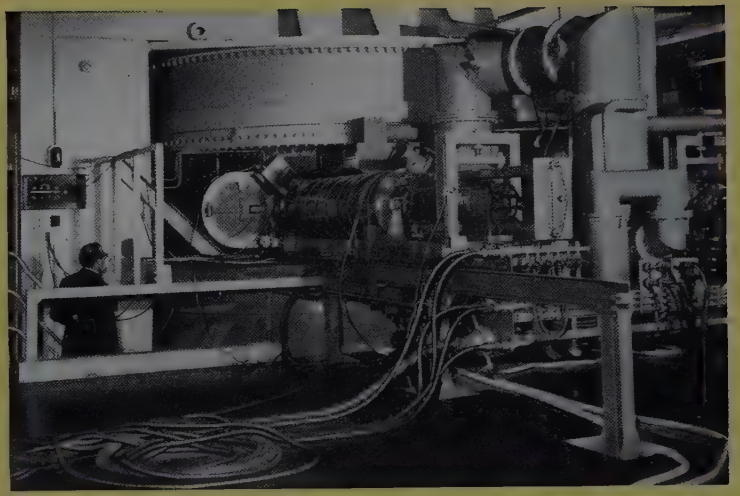

FIGURE 4 – *The 110-inch Harwell synchrocyclotron.*

FIGURE 5 – *The Glasgow electron synchrotron.*

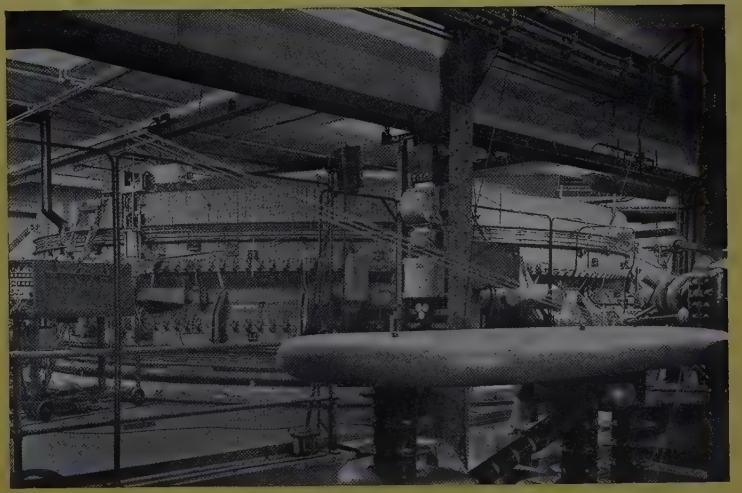

FIGURE 6 – *The Birmingham proton synchrotron.*

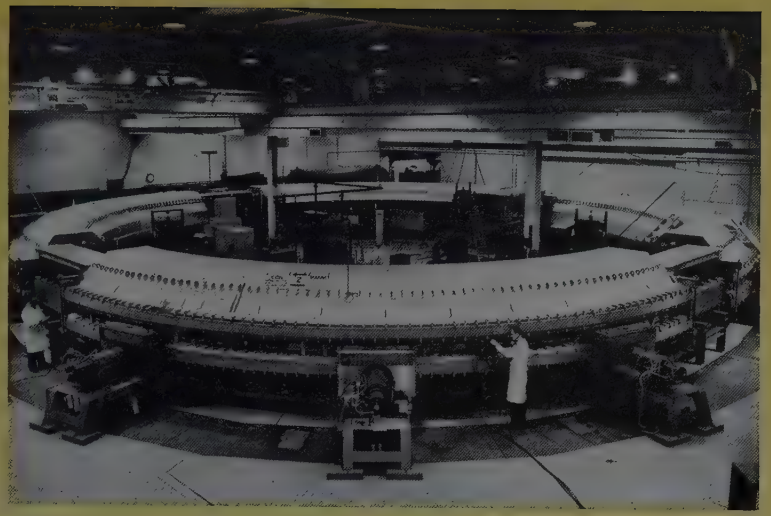

FIGURE 7 – *The Brookhaven proton synchrotron (Cosmotron).*

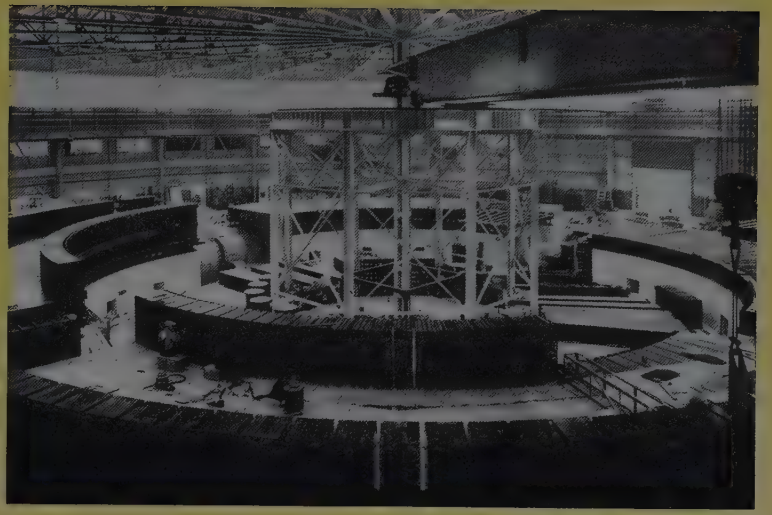

FIGURE 8 – *The Berkeley proton synchrotron (Bevatron), shown under construction.*

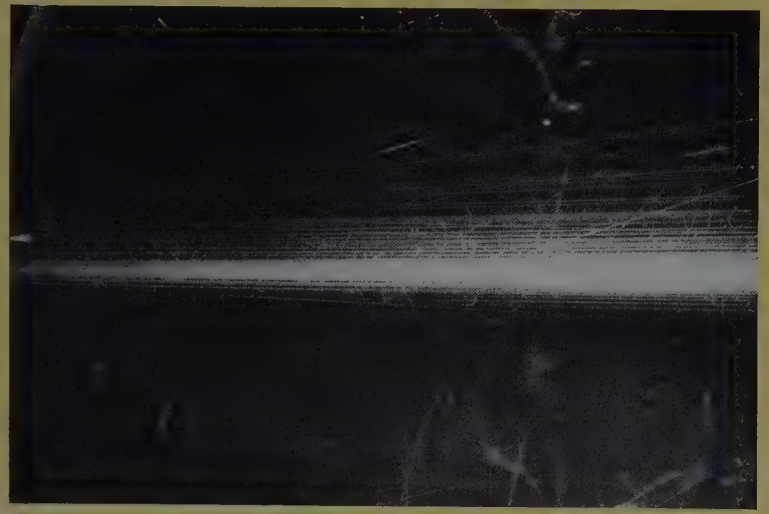

FIGURE 9 – *Tracks in a diffusion cloud chamber irradiated by 150 MeV protons from the Harwell synchrocyclotron.*

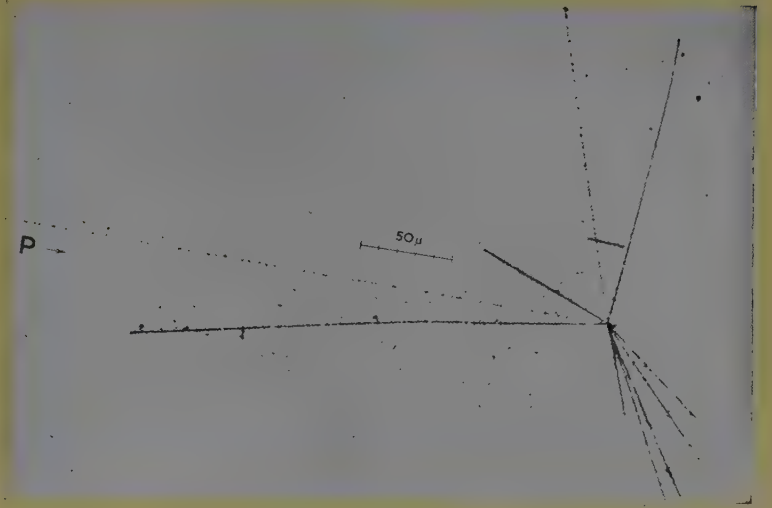


FIGURE 10 – *Nuclear disintegration caused by a 1 GeV proton. Tracks produced in a nuclear emulsion exposed to the beam of the Birmingham proton synchrotron.*

is a photograph of tracks made in a diffusion cloud chamber by 150 MeV protons from the Harwell synchrocyclotron.

The second development in this field is a very recent one. Physicists at Brookhaven, Chicago, and Berkeley have developed the 'bubble chamber' technique, in which bubbles of vapour form along the track of an ionizing particle in a superheated liquid. The superheated condition is achieved by making a carefully controlled and timed reduction of pressure. Considerable success has been achieved with liquid pentane, and some success with liquid hydrogen. So far, the biggest chambers are only a few centimetres across, but the great density of the medium is an enormous advantage in work with high-energy particles.

The nuclear emulsion technique has the advantage of employing a medium of very high density, but the bulk of the material consists of silver and bromine, together with carbon, hydrogen, and oxygen, so that this method is less flexible. The modern development of the technique was pioneered by Powell's group at Bristol, for application both to cosmic ray research and to work with accelerators.

Figure 10 shows a 'star' observed in a nuclear emulsion exposed to the beam of the Birmingham proton synchrotron. A nucleus in the material of the emulsion has been highly excited by the impact of the energetic primary particle (a 1 GeV proton), and the energy of excitation was sufficient to disrupt the nucleus into several fragments, which moved away with considerable velocity. The nine charged fragments left tracks visible under the microscope after development of the emulsion. Uncharged particles leave no record in the emulsion, but some would undoubtedly be produced in a disintegration of this magnitude.

The Cosmotron group at Brookhaven has been able to demonstrate the artificial production of some of the new particles identified in cosmic rays, using both cloud chamber and emulsion techniques. They have observed many cases of $\Lambda^0$ and $\theta^0$ particles in the diffusion cloud chamber, and some of their photographs show the decay products of one of each of these particles, presumably produced in the same event. $\Lambda^0$ particles have a mass somewhat greater than that of the proton, are uncharged, and decay into a proton and a negative π-meson. $\theta^0$ particles have a mass about 1000 times the electron mass, are also uncharged, and decay into a positive and a negative π-meson. The double events were observed when the hydrogen-filled diffusion chamber was exposed to a 1·5 GeV negative π-meson beam emerging from a target bombarded by protons in the Cosmotron. The following reaction is presumed to have occurred:

$$\pi^- + p \rightarrow \Lambda^0 + \theta^0$$
$$\downarrow \qquad \downarrow$$
$$p + \pi^- \qquad \pi^+ + \pi^-$$

The four decay-product particles are identifiable from studies of the photographs.

There is a large class of 'heavy mesons' discovered in cosmic ray research and known collectively as K-mesons. The $\theta^0$ particle is an uncharged member of this family, but there are believed to be several charged varieties with masses about 1000 times the electron mass. Several kinds of charged K-mesons have already been observed in studies of nuclear emulsions exposed to the beam of the Cosmotron.

The situation with regard to these newly discovered particles is very complex, but it is certain that knowledge of their properties and the conditions under which they may be produced will rapidly expand as work proceeds on the large accelerators. All the unstable particles so far known have been discovered in studies of cosmic rays, with the exception of the $\pi^0$ meson (which was very nearly discovered by Powell's group!), but the more intense beams produced by accelerators have proved to be essential in studying the production and properties of mesons and their interaction with other particles. In this sense cosmic ray research and accelerator research have been truly complementary.

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# Determination of the absolute configuration of optical antipodes

J. M. BIJVOET

Optical antipodes have atomic arrangements that are the inverted images of each other. Although the nature of atomic arrangements can be determined in all minor details, the problem of which of the two possible configurations corresponds to a particular compound long remained unsolved. X-ray analysis, however, has now provided a means of establishing this 'absolute' configuration, although it at first seemed incapable of doing so.

The relative positions of the atoms in a large organic molecule can be determined in two entirely different ways. The chemical method involves the determination of the atomic arrangement by breaking the molecule into smaller fragments, the structures of each of which have already been established by similar means. The determination by this method of the atomic pattern of hundreds of thousands of compounds, from very simple ones to complicated alkaloids and hormones, is one of the major achievements of science. Van 't Hoff's concept of the tetrahedral carbon atom made possible the extension of structural formulae to include spatial configuration.

The second, non-destructive, method of determining atomic order is X-ray analysis. The gas or crystal is exposed to a beam of X-rays, and the resulting diffraction pattern is recorded. Each atom causes uniform scattering of the incident rays in all directions, and the waves scattered by the different atoms of a molecule or a crystal interfere. For each direction of diffraction the waves originating from the various atoms have path (phase) differences. These path differences determine the effect of the interaction of the various waves and the resultant intensity in each direction. As these path differences depend, in turn, on the magnitude and orientation of interatomic distances, it is possible to calculate the atomic configuration from the diffraction intensities forming the X-ray pattern.

It is gratifying to find that these two entirely different methods lead to essentially the same results. X-ray analysis leads to a scaled and geometrically exact structural model, in which the interatomic distances may be indicated with an accuracy of a hundredth of an Angstrom. Unlike chemical determination methods, X-ray diffraction permits the study, under favourable conditions, of an arbitrarily chosen compound, without need of any knowledge of allied substances. When, for example, Gammexane, one of the stereo-isomers of benzene hexachloride, was found to possess insecticidal action, attention was suddenly focused on its configuration, which X-ray analysis determined directly, as opposed to its molecular structure. On the other hand, determination of the structure by chemical methods, which has also recently been achieved, required a fairly extensive study of the various stereo-isomers, and of a number of hepta- and octa-chlorocyclohexanes.

As molecular structure can be established in minute detail, by either chemical or X-ray methods, it is surprising to find that neither method was able to provide an answer to the question which is discussed in the present article.

It is common knowledge that there are compounds whose crystals, or even molecules in solution, rotate the plane of polarization of light. These compounds occur in two forms, which are distinguished by the fact that one rotates the plane of polarization to the right (positive rotation), and the other to the left (negative rotation). In denoting these optical antipodes the name is accordingly prefixed by (+) or (−) respectively. Classical examples are (+) tartaric acid and (−) tartaric acid; (+) quartz and (−) quartz. Neither the crystals nor the molecules of these optical isomers are superimposable; they are mirror images of each other. An example of this is shown in figure 1, where the left-hand model is denoted by D, the second by L.

As we have seen, it is possible to determine the molecular structure of all optically active compounds, but surprisingly enough we cannot state which of these two models, D or L, corresponds to the dextrorotatory antipode and which to the laevorotatory one. Before discussing how this

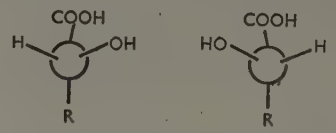


FIGURE 1 – *α-substituted acids are conventionally given the prefix D if the α-substituted group points to the right when the —COOH group is at the top and —COOH and —R point backwards.*

problem may be solved it is appropriate to discuss the factors which create it.

## CHEMISTRY AND ABSOLUTE CONFIGURATION

Chemistry determines the relative behaviour of compounds, i.e. the relationships between different structures. Consequently, it is not possible to detect by chemical means the changes that would occur if all optical antipodes assumed or possessed their inverted configurations. It is possible, however, to determine the relative configurations of allied optically active compounds. Thus we can ascertain whether, for instance, (+) lactic acid ($CH_3CHOH\,COOH$) corresponds, in the configuration of its four groups round the asymmetric carbon atom, to (−) or to (+) alanine ($CH_3CHNH_2COOH$).

It appears that direct substitution of —OH or —$NH_2$ at the asymmetric atom may be accompanied by inversion of the configuration (Walden inversion). The generic relation does not, therefore, lead to a decisive conclusion regarding the relative configuration. A way of determining the latter is to effect in each of the two compounds the same chemical change in one of the substituents bound to the asymmetric carbon atom.

Such a substitution may be expected, for corresponding configurations, to bring about analogous changes of the rotation. Table I shows that in fact (+) alanine has the same configuration as (+)

TABLE I

| *Derivative* | (+) *lactic acid* | (+) *alanine* | (−) *alanine* |
|---|---|---|---|
| Amide of the benzoyl compound | + 120° | + 70° | − 70° |
| Ethyl ester of the benzoyl compound | + 49° | + 12° | − 12° |
| Methyl ester of the benzoyl compound | + 35° | + 4° | − 4° |
| Ethyl ester of the acetyl compound | − 76° | − 74° | + 74° |
| Ethyl ester of the toluene sulphonyl compound | − 129° | − 78° | + 78° |

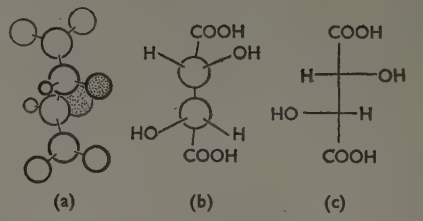


FIGURE 2 – *Absolute configuration of natural dextrorotatory tartaric acid.* (a) *As determined by X-rays in sodium rubidium tartrate.* (b) *In normalized configuration, by rotating around single bonds.* (c) *In projection.*

lactic acid. Thus a relationship is established between the configurations of the amino acids and of the oxy-acids.[1]

It is generally known that these relative configurations are of the utmost importance to the course of reaction between optically active compounds. In order to facilitate expression of these relationships Emil Fischer arbitrarily assigned the configuration of figure 2(*b*) to one substance, viz. to natural dextrorotatory tartaric acid. There is an even chance that this choice represents the true situation.

It may be true that only the relative configurations, and not the right choice of the absolute ones, are of vital importance to chemistry. Yet the advantages of knowing the absolute configuration are not limited to the mere satisfaction of knowing, nor to a didactic simplification resulting if reality, instead of arbitrary convention, can serve for assigning structures and as a basis of nomenclature. A direct method of determining absolute configuration has practical importance for establishing or confirming relative configurations in cases where chemical methods present difficulties. As an example of these difficulties we may again mention the uncertainty whether substitution of one of the groups about an asymmetric carbon atom causes the configuration to be inverted or not.

## OPTICAL ROTATION AND ABSOLUTE CONFIGURATION

An obvious physical method for determining absolute configuration is the theoretical calculation of the rotation of the plane of polarization of

[1] A direct method for relating two compounds from different optically active series is to incorporate their asymmetric atoms into one molecule. It has, for instance, been demonstrated—X-ray analysis leaves no doubt whatever in this respect—that the —OH and —COOH groups in hydroxyproline are in the *trans* position. This, again, establishes the relationship between α-oxy- and α-amino acids.

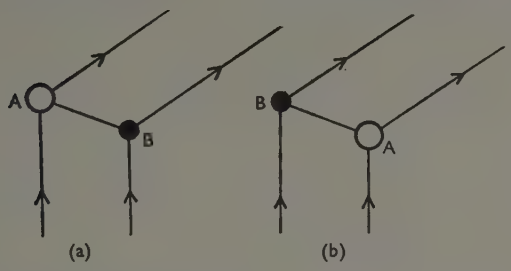


FIGURE 3 – *Diffraction by a molecule AB and its inverse configuration BA respectively.*

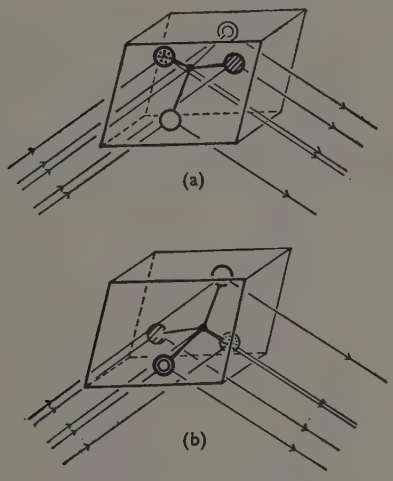


FIGURE 4 – *Diffraction by asymmetric molecule. Cf. figure* 1.

polarized light.[1] Starting from one of the mirror images, it is computed whether this configuration should give laevo- or dextro-rotation. A number of workers, especially during the years 1935–40, made calculations of optical activity on the basis of a number of theories (Kuhn [1], Eyring [2]). However, there being no sufficiently clear picture of the details of the atomic structure, there was no agreement between the results. Work carried out in this period on particular molecules, for example methylethylcarbinol, led to results that even differed in sign [3].

In the last few years interesting calculations have been carried out—including calculations with two or more related compounds—which can probably be considered reliable (Kirkwood, Looyenga, [4]). In agreement with Kuhn's result, they confirm Fischer's arbitrary convention as representing, in fact, the true situation.

Crystals, as well as liquids, have been the subject of computations. It seems reasonable to suppose that a pronounced right-handed spiral structure in the crystal corresponds to a rotation to the right, looking in the direction of propagation of the light (Wooster [5]).

## NORMAL X-RAY DIFFRACTION AND ABSOLUTE CONFIGURATION

The essential difficulty in the X-ray determination of the absolute configuration is explained in figures 3–5. Figure 3(*a*) shows the diffraction of an X-ray beam caused by a molecule AB, and 3(*b*) the diffraction caused by its inverted configuration BA, where only the sense of the direction of the line BA has changed.

While in the situation indicated in figure 3(*a*) the rays diffracted by atom A have the smaller path length, in figure 3(*b*) they have the longer path. However, as regards its absolute value, the difference in path length between rays diffracted by A and B is seen to remain unchanged. This causes the resultant intensity to remain unchanged. As this holds good for any direction of diffraction, the two situations are indistinguishable by simple X-ray analysis.

It holds good, too, for inversion of any structure. A structure is inverted by connecting each of its points P with an arbitrarily chosen centre O and by extending line PO by its own length to P′. All points P′ together give the inverted image. Just as in figure 3, the line connecting two points then changes only in sense. Hence, on inversion of a structure the phase difference involved in the interference is exactly inverted for each pair of atoms; consequently their contribution to the interference, and therefore to the diffraction intensity, remains unchanged.

A certain set of intensities may thus be caused either by a structure A or by the inverse structure A′. X-ray analysis cannot therefore distinguish inverse structures. In the case of optical antipodes the inverse structure, as is shown by figure 5, is the other antipode in a related orientation; therefore X-ray analysis cannot distinguish optical antipodes.

## ANOMALOUS DIFFRACTION

It is curious to note that an assumption introduced here was discussed in the early days of X-ray analysis and found to be not universally

[1] Another obvious method is to ascertain whether the face development in the crystal of an antipode is more consistent with one configuration than with the other. However, such a derivation from the growth-rate of crystal planes is extremely difficult and has not led to a reliable conclusion.

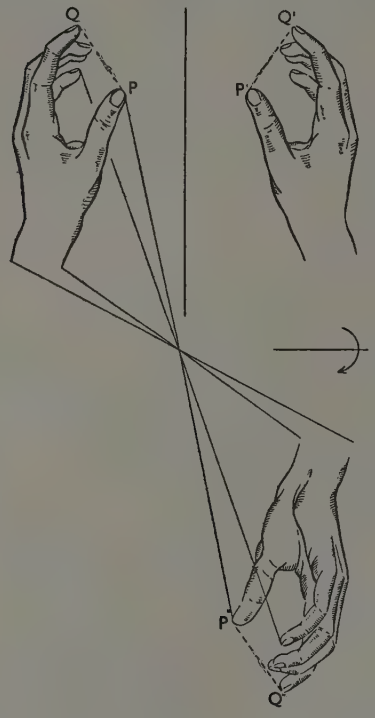


FIGURE 5 – *Inversion is equivalent to reflection combined with rotation through* 180° *about an axis normal to the reflection plane. This results in formation of the opposite antipode.*

valid. The assumption is that the phase difference between the waves originating from two atoms '*nur von dem Unterschiede des durchlaufenen Weges abhängt und dass die Natur des Atoms auf die Phase keinen Einfluss hat*' ('depends only on the path difference and that the nature of the atoms has no influence on the phase') (W. L. Bragg [6]). The question is whether or not a phase shift occurs at the diffracting atom (or may occur under special conditions), between incident and emitted radiation, and to what extent this phase shift, which is equivalent to an apparent reduction of the real path-length, may affect the above considerations. In the mutual phase differences between the waves diffracted by the various atoms this phase shift is, of course, neutralized as long as it is equally great for all these atoms, i.e. as long as '*die Natur des Atoms auf die Phase keinen Einfluss hat.*' However, although the latter appears to be the rule under 'normal' conditions, it is not universally true.

It is the electrons in an atom that the incident X-rays cause to vibrate and to radiate. As long as the electrons can be considered to be weakly bound, they vibrate in opposite phase to the incident rays.[1] Only in heavy atoms do the strongly bound electrons of the inner shell (K electrons) vibrate in phase with the incident wave.[2] Such an exact counteraction within the atom between the diffraction of K electrons and that of the other electrons does not alter our argument in any respect; it only changes to some extent the magnitude of the diffracting power of the atom.

As far back as 1916 Von Laue [7] wrote: '*Es wäre eine interessante Frage für den Versuch, ob sich nicht, namentlich bei stark absorbierenden Kristallen, und wenn die Frequenz der einfallenden Strahlung nahe einer Eigenfrequenz des Atoms liegt, doch Ausnahmen feststellen lassen.* ('It would be an interesting subject for experiment, in particular for strongly absorbing crystals, to see whether an exception could be established in cases where the frequency of the incident radiation lies near a natural frequency of the atoms.')

The situation may be elucidated with the aid of an analogy. Let there be a pendulum which, by coupling, imparts its vibration to another (figure 6). If the latter has a lower natural frequency—longer pendulum B, weaker 'bond'—it starts vibrating in opposite phase. If it has a higher natural frequency—shorter pendulum C, stronger 'bond'—it starts vibrating in phase. There is therefore complete analogy with X-ray vibration, represented by A, causing a weakly or a strongly bound electron to resonate.

Let us suppose that the exciting vibration, starting from a high frequency, decreases in frequency. In the case of the pendulum the imparted vibration undergoes the phase shift of 180° exactly at the point where the frequency of the incident vibration corresponds with the natural frequency of the pendulum. In the case of the atom the situation is slightly different. Here, too, incident radiation of high frequency causes all electrons to vibrate in phase opposite to that of the incident rays. If the frequency of the latter decreases, it approaches the range of natural frequencies of the K electrons. However, in an atom the electrons are not bound by any one frequency, but the binding of the K electrons is characterized by the range of frequencies that may excite these electrons and shift them to available orbits. If the

[1] This is because the acceleration will be in phase with the electric force, but the acceleration and deflection of a vibration are in opposite phase.

[2] This is because here the electric force must, at any given moment, essentially compensate the binding force.

frequency of the X-ray beam falling upon the atom approaches and passes through this absorption zone, it was expected—and was later confirmed by quantum-mechanical calculations—that the phase of the co-vibrating K electron will change gradually.

It is these phase shifts at the diffracting atom, deviating from π or zero and referred to by Von Laue, that permit determination of absolute configuration by X-ray analysis.

### ANOMALOUS DIFFRACTION AND FRIEDEL'S LAW

Not until 1930 was the test suggested by Von Laue actually carried out. It was done to check the so-called Friedel's law, which expresses the equivalence of reflection and counter-reflection, i.e. the effect at the diametrically opposed sides of a crystal (figure 7). Their equivalence follows naturally from considerations of symmetry if, as in figure 7(*b*), there is no difference in the succession of the planes from below upwards or from above downwards. In the case of a polar succession, as in figure 7(*a*), there is, however, no consideration of symmetry that precludes a non-equivalence of reflection A and counter-reflection A′.

It is true that Friedel was initially of the opinion that '*les deux rayons A et A′, identiques par symétrie dans le cas de l'holoédrie, restent forcément identiques par symétrie dans le cas de l'hémiédrie*', ('the two rays A and A′, identical by symmetry in the case of holohedrism, necessarily remain identical by symmetry in the case of hemihedrism'), but it was soon demonstrated that this '*forcément*' was not well founded.

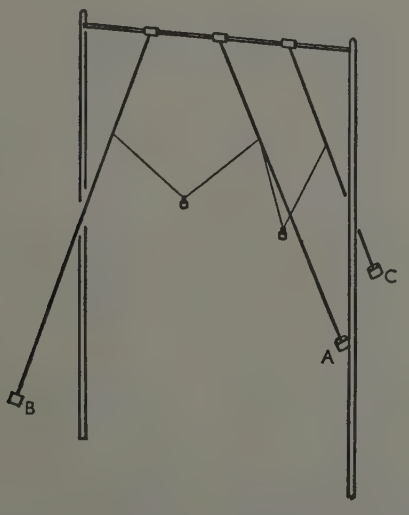


FIGURE 6 – *The pendulum A excites the longer pendulum B and the shorter pendulum C. B oscillates with opposite phase, C in phase.*

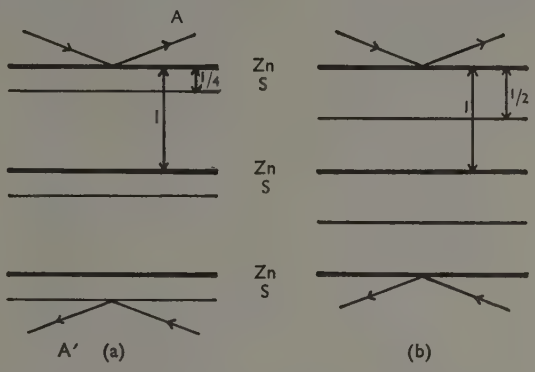


FIGURE 7 – *Reflection and counter-reflection from a polar* (a), *and a non-polar* (b), *succession of crystal planes.*

Coster, Knol, and Prins [8] measured the intensity of reflections A and A′ for such a case as that shown in figure 7(*a*), which depicts a zinc blende crystal with tetrahedral planes alternately filled with Zn and S atoms. The distances between successive Zn and S planes is one-quarter of the period ZnS—ZnS. . . . In the so-called first-order reflection the path difference between the rays reflected by successive zinc planes is λ, and that between rays reflected by successive Zn and S planes is therefore λ/4.

For radiation of arbitrary wavelength the difference in phase shift is the same at the zinc atom as at the sulphur atom. Consequently, with reflection A the wave reflected by the zinc plane leads the wave reflected by the sulphur plane by 90°, whereas with reflection A′ it lags 90° behind. Composition of the two waves gives the same resultant intensity, in spite of the polar succession which, again, causes only the sign of the phase difference to change. Normal X-ray reflection does not detect any difference between one side, a dull and poorly developed tetrahedron plane, and the other, a shining and well-developed one. In this respect it is less sensitive than the human eye.

Coster, however, chose a radiation—$L\alpha_1$ radiation of gold—which just excites the K electrons of zinc. In this anomalous scattering the phase at a zinc atom gets a lead when compared with the wave at a sulphur atom. Let us suppose the magnitude of this lead to be 10°; this is about the value that can be expected theoretically.

For reflection A the total phase difference that is active in the interference is then 90° + 10° = 100°, instead of 90°. For the reflection B it is

$-90° + 10° = -80°$. The combination has therefore been shifted in the direction of counteraction (180°) in A, but in the direction of reinforcement (0°) in A′. A must therefore have a lower intensity than A′. Coster *et al.* have succeeded in demonstrating this difference.

Now X-ray analysis not only detects a difference, but it concludes—and this is, of course completely impossible for the human eye—that it is the dull plane that has the Zn side facing outwards: for the dull plane is found to give the weakest reflection and, as has been argued, the weakest reflection is that from the Zn-plane (figure 7(*a*)).

Friedel's law being shown not to hold good, it is possible to determine whether the crystal is being viewed in the ZnS—ZnS direction or in the SZn—SZn direction. This can be generally expressed by saying that the polarity of an atomic succession can be determined with the aid of anomalous diffraction.

As has been stated above, in normal diffraction X-rays do not detect any difference between right-hand and left-hand antipodes. In this respect they are inferior to the human eye. It will be shown, however, that anomalous diffraction is even capable also of assigning to them their absolute configuration.

## ANOMALOUS DIFFRACTION AND ABSOLUTE CONFIGURATION

From 1930 to 1950 knowledge that Friedel's law does not hold good in the case of anomalous diffraction went side by side with the idea that it was fundamentally impossible to determine absolute configuration by means of X-ray analysis. However, figure 8, (*a*) and (*b*), shows the identity of this problem with that of figure 7(*a*). In both cases a polar succession of atomic planes is involved, and it is the sense of this succession which must be determined.

Whether or not a structure is involved which, on inversion, is superimposable on itself—ZnS case and identification of antipodes respectively—is irrelevant. If the antipodes are in inverted positions the reflections become unequal in intensity—and the structures become distinguishable—if in the phase difference between two atoms,

$$(\varphi_B - \varphi_A)_{total} = (\varphi_B - \varphi_A)_{path\ difference} + (\varphi_B - \varphi_A)_{primary\ diffraction\ process},$$

the last term is not zero (anomalous diffraction). Consequently, the total phase difference does not merely change its sign when the path differences do so.

Let us imagine that a normal structure determination of an optically active compound has been performed; it results in the structure being defined except for possible inversion. Calculation will show for which of the two (dextro or laevo) configurations the intensity of a certain reflection will increase, and for which it will decrease, when a radiation is used that just excites one of the atoms. Measurements of this anomalous reflection for the two antipodes[1] then make unambiguous assignment of configuration possible.

TABLE II

*Calculated intensities of normal and anomalous diffraction (RbH tartrate)*

| *Indices of reflection plane* | *Calculated intensities* | | |
|---|---|---|---|
| | *D-model anomalous diffraction* | *Normal diffraction* | *L-model anomalous diffraction* |
| 113 | 281 | 313 | 351 |
| 114 | 412 | 385 | 369 |
| 123 | 371 | 420 | 482 |
| 124 | 226 | 217 | 212 |
| 125 | 63 | 55 | 52 |
| 126 | 159 | 152 | 147 |
| 135 | 227 | 250 | 278 |
| 141 | 239 | 223 | 209 |
| 143 | 188 | 165 | 149 |
| 146 | 80 | 82 | 93 |
| 151 | 359 | 333 | 316 |

It is curious to note that the significance of the ZnS case for the determination of absolute configuration became apparent only when it revealed itself most strikingly, viz. in the Fourier synthesis of an optically active compound. The mirror images here differ in the location of the maxima of the density waves on one side of the origin or on the other. This ambiguity in the sequence of the density planes immediately reminds one of that shown in figure 7(*a*).

[1] It is easily understood that the intensity of a reflection remains unchanged if both structure and direction of X-rays are inverted ($I_b = I_c$, figure 8). Instead of comparing the same reflection at the two antipodes (figure 8a → b) one really compares the anomalous intensities of reflection and counter-reflection at one antipode (a → c). Not only does this measurement require only one antipode, but it is also more accurate because it is done with the aid of one crystal on one film.

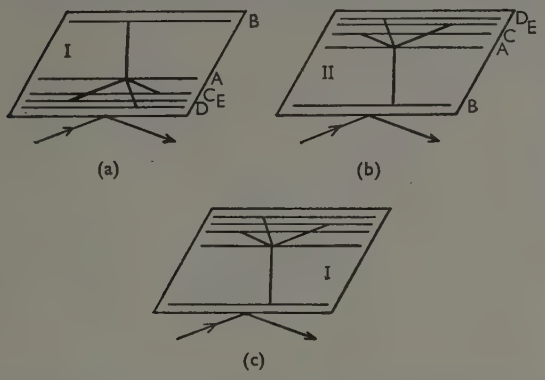


FIGURE 8 – (a) *and* (b) *are as in figure* 4; *through each atom a plane has been drawn parallel to the reflecting plane. In* (b) *the order of the planes DECAB is inverted with respect to* (a); (c) *is the counter-reflection of* (a).

Table II shows the effect of anomalous diffraction in the case of sodium rubidium tartrate dihydrate ($NaRbC_4H_4O_6.2H_2O$), in which the Rb atom was excited by ZrK radiation.

Table III shows the compounds whose absolute configurations have so far been determined. The characteristic radiation was obtained by means of a tube with a special anode (Zr, U). Recently, however, radiation of the desired wavelength has been obtained from the continuous radiation of a normal X-ray tube (Grenville-Wells and Lonsdale [10]); the reflecting plane is made to select the desired wavelength. This makes it possible to approach the absorption limit of any atom as closely as we like.

TABLE III

| *Compound* | *Excited atom* | *Radiation used* |
|---|---|---|
| NaRb tartrate 2 aq. [11] .. | Rb | ZrKα |
| RbH tartrate [12] .. .. | Rb | ZrKα |
| *iso*leucine HBr 2 aq. [13] .. | Br | UL |
| $2[CoEn_3]Cl_3.NaCl.6H_2O$ [14] .. | Co | CuKα |

Dextrorotatory tartaric acid thus appears to possess the configuration of figure 2, so Fischer's arbitrary convention is proved to correspond with reality.

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# The colour changes of cephalopods

WILLIAM HOLMES

The striking colours, and amazingly rapid colour changes, shown by cephalopod molluscs are little known, though in many ways they are more beautiful than the familiar forms of animal coloration. The biologist certainly regards them as unique, for the mechanism behind the colour change is found in no other group of the animal kingdom. As many of the colour patterns are of extremely brief duration, much interest attaches to the accompanying illustrations.

The cephalopods are so called because they have developed long 'limbs' near the mouth, a feature which is among those distinguishing them from lower molluscs, such as snails. The octopod molluscs (e.g. *Octopus*) use these structures both as arms in feeding, and as legs in locomotion. The decapods (e.g. *Sepia*, the cuttlefish, and *Loligo*, the squid) use them as arms only, and move themselves about either by the undulations of a fin which runs down either side of the body or by the expulsion of a jet of water from one of the body-cavities.

The most primitive molluscs undoubtedly had a shell, which is a protection against many sorts of predator. But a shell is a cumbersome thing, restricting activity, and the evolution of the group involved exploring new food sources inaccessible to an animal with a heavy shell. Accordingly the cephalopods developed the arms and the jet-propulsion mechanism; at the same time they gave up the shell as a protection. In decapods the shell remains only as the 'cuttle-bone,' lying below the skin; this gives little protection, for it does not cover the head.

The power of changing colour is a new, alternative, protective device, and since it was acquired by molluscs late in their evolution it is not surprising that it is brought about by a unique mechanism. Other animals use colour and colour change as a means of stimulating, deceiving, or frightening each other or their predators or their prey, but the underlying processes are different.

Sometimes the body of a recently dead cuttlefish or squid is found on the sea-shore; even if it has been dead for some hours the chromatophore activities which are the basis of colour change may still be seen taking place: waves or clouds of colour pass over the surface of the body, changing continuously and in a matter of seconds. The waves of colour show variations on black, brown, red, and yellow. The general effect is the result of the activity of large numbers of individual coloured bodies in the skin—red, brown, or orange-yellow —on a background of pearly, iridescent white. Each of these bodies varies in size from an almost invisible pinpoint to a maximum which depends upon the species, but is as big as a pin's head or larger.

The chromatophores have been studied for many years, and it has long been known that each is a hollow sac with elastic walls, containing pigment granules; the chemical composition of these is still not known with certainty. Connecting the outer wall of the sac with the adjacent tissues are fibres of unstriped muscle radiating outwards in the plane of the surface of the body. Contraction of the fibres pulls the sac outwards into a flat disk, spreading its coloured contents over a wide area; when contraction of the fibres ceases, the elasticity of the sac reduces it again to a pin-point sphere [6]. Many studies have been made of the physiological properties of these minute muscle fibres. The rate of expansion of a chromatophore may be measured photo-electrically; the change from complete contraction to full expansion can occur in two-thirds of a second. The muscle fibres seem immune to fatigue, for their response is undiminished after effective stimulation for thirty minutes at a frequency of thirty shocks per second [4].

The chromatophores lie in three layers in the skin, the yellowish ones on top, the red in the middle, and the brown or black below [6]; they overlap each other when expanded, and consequently various compound colour effects result. The pearly background colour is the result of reflection of light from a layer containing structures of a different character, called iridocytes [7]. These are incapable of changing shape, but on certain areas of the body they are aggregated into clumps, which shine clear white; these, as we shall see, play a part, with the chromatophores, in the formation of colour patterns. Some of the clumps of iridocytes are, in a sense, mobile, for the

skin containing them may either lie flat along the body or be arched up into conspicuous papillae.

### PROTECTIVE COLORATION

Animal colours can be classified into several categories according to their adaptive value; that is, according to the way in which they affect other animals of the same species, or animals of a different species in the same environment. Thus, its colour may cause an animal to resemble features of its immediate environment, rendering it more or less invisible to its enemies, who cannot distinguish it from other adjacent, inedible objects. Resemblance to its surroundings is equally valuable to an animal which is a predator, for then it can steal upon its prey unobserved. Again, we may have warning coloration: an individual may be equipped with bright colours, or colours arranged in striking patterns which are associated with effective weapons of defence or the ultimate protection of nauseous taste, or inedibility. By this last device the predator is trained to avoid other members of the race, though the individual is sacrificed. Another use of colour is that associated with the breeding habits of the animal, in which a particular play of colour, or a particular pattern, affects members of the opposite sex of the species, or competing members of the same sex.

The demonstration that the colours of a particular animal have a biological significance in any of these ways requires experiments on behaviour in which the animal itself, and its predators, prey, or mates are concerned. These are often difficult to devise, and since of all cephalopods the octopus is the only one which will live happily in an aquarium, information on this group is particularly meagre. Thus we have little certain knowledge of what animals are the chief predators of the cuttlefish; the remains of cephalopods occasionally found in the stomachs of fish or crustaceans may be of meals taken from dead or dying animals, and in consequence irrelevant to the problem of the normal predator. Scattered observations, made by naturalists over more than a century, leave the impression that it is mainly the aquatic mammals, such as dolphins and porpoises, that eat the active cuttlefish as a regular part of their diet. In the absence of experimental evidence we are bound to fall back on human judgment of the protective and warning significance of colour patterns, but we can also take into account evidence derived from more accessible examples of the phenomena associated with coloration, as in butterflies, reptiles, and birds. Fortunately, we have, from direct observations of mating behaviour [1, 8], more direct evidence of the sexual function of colour in cephalopods.

### COLOUR PATTERNS OF THE CUTTLEFISH

A cuttlefish swimming undisturbed in a large aquarium shows a 'zebra' pattern. Down both sides of its back run broad stripes, alternately dark brown and almost white (figure 5); similar stripes appear over the large lateral arms, one of which can be seen from the side in the same figure. It can also be seen that the fin, which was in motion, has a pale brown mottling, and that the underside of the body is white. In the black stripes the dark chromatophores are almost fully expanded; in the pale areas they are fully contracted. The pale areas vary in colour from orange to white, according to the degree of expansion of the lighter-coloured chromatophores; the purest white is seen when the light is almost all reflected from the iridocytes beneath. An area in the middle of the back, shaped like the cuttle-bone and lying over it, is mottled in colour when the animal is in a small tank which obliges it to be always near the bottom or sides. In a large tank, the zebra stripes pass over the whole of the dorsal surface, though they are narrower over the cuttle-bone. Figure 5 shows also that white circular areas, at the base of the fin, are an element in the pattern.

The ventral surface of the body is pale, and this difference between upper and lower surfaces demonstrates the first principle of protective coloration: that of 'obliterative countershading'. The dorsal surface receives most incident light, and reflects least; the ventral surface is in the shadow, and reflects almost all the light that falls upon it. This counteracts the normal effects of light and shade, which give the appearance of solidity to a body; thus the animal is protected by an artificial vagueness given to its form. If a cuttlefish is turned upon its back, as it must often be when fighting, the dark chromatophores of the ventral surface instantly expand, and so minimise the dangerous conspicuousness which would otherwise arise when the light fell on its white belly. The protective value of the black and white stripes needs no emphasis; these serve, as they do for the Zebra, to disrupt the shape of the body, and so to make it inconspicuous. The cuttlefish often swims among beds of waving seaweed, and when near the surface ripples of light and shade fall on it, adding to the deception.

Another environment in which cuttlefish are often found is shallow coastal water where the sea-floor

is sandy or composed of shell gravel. When swimming close to such a bed the animal modifies its stripe pattern by a partial contraction of the dark chromatophores and further expansion of those of lighter shade. Thus it comes to match its background, having much less contrasted stripes, of a sandy colour, on its back, resembling the play of light on the sandy sea-bed. If it settles down on the sand the stripes disappear altogether, leaving a mottled pattern of an appropriate matching colour, resulting from reflection of light from the three types of chromatophore, variously expanded, in irregular patches (figure 1). This pattern covers the head and arms as well as the back.

We now come to the white-square and stripe patterns, which can easily be elicited from animals in a small tank. If one blackens the floor and walls of the tank a cuttlefish placed in it receives comparatively little incident light. Its response is to become uniformly very dark in colour, by full expansion of the black chromatophores; it is thus made inconspicuous. If now a white object, such as a porcelain plate, is introduced, clear white areas appear on the body. Three main elements may be distinguished in the black-and-white pattern; a stripe across the head above the eyes; a square in the centre of the back; and symmetrical white bands extending down at either side of the back from the central square (figures 6–9). As can be seen in these figures, the square may appear either with or without the white stripes. As protective devices these patterns are useful both by giving a resemblance to the environment and by disrupting the outlines of the body. They are often accompanied by another kind of white pattern on the black background, brought about by the muscular elevation of papillae containing a concentration of iridocytes; these arise in regular positions along the base of the fin (figure 7). An interesting condition is seen in figure 9. Here the animal is passing directly from the sandy stripe pattern to the white-square pattern, having just been introduced into the dark tank, and the square is appearing first on the half of the body on which is the eye closest to the white plate.

Perhaps the most remarkable of all are the 'terrifying' patterns, which appear and disappear with lightning rapidity. Strong stimulation of the cuttlefish is followed by a series of colour changes of remarkable rapidity, involving the whole body of the animal. A succession of patterns is exhibited, each one enduring for a few seconds only. A strong touch, a violent movement in the visual field, or a disturbance of the posture of the animal, are each sufficient to elicit these changes.

Usually the first result of disturbing the animal is the appearance of two black spots, which arise symmetrically on the back, always in the same position (figure 4). If the animal is fairly gently stimulated, a single spot will appear on the same side of the body as that to which the stimulus was applied. The appearance of the black spots is very soon followed by a total paling of the whole of the rest of the body, so that the spots stand out with startling clarity. This pallor is rarely maintained for more than a second or two, being usually succeeded immediately by a complete change, the total blackening of the body. On further irritation a new pattern may appear: two longitudinal black stripes appear on the back, and the rest of the body turns white again. The lines flicker vividly over the pallid back. The animal's final resource is to eject a cloud of 'ink'; having done this it becomes motionless, and hides inside the black cloud. The cloud remains suspended in the water for a considerable time, and makes further observation of the colour of the animal itself impossible. The sudden display of a conspicuous pattern of colour is known, among other animals, to be a form of warning coloration. The 'terrifying' displays of the cuttlefish may also protect it in another way. The rapid changes from black to white make the animal seem to disappear, even to the acute human eye, and the sudden movement of the conspicuous coloured shapes may startle and divert the predator.

Each particular situation in the cuttlefish's life evokes characteristic colour behaviour; those which accompany mating have been described by R. Bott [1] and L. Tinbergen [8]. No other cephalopod has as extensive a repertoire of patterns. The octopus shows some comparable changes (figures 2 and 3); but the squids, which live in deeper water, though capable of generalized changes, cannot produce conspicuous patterns. These open-ocean creatures often show instead patterns of luminescence in the dark [3], but they are so difficult to keep alive in aquaria that few have studied them.

## THE CENTRAL NERVOUS SYSTEM AND COLOUR CHANGE

The little muscle fibres whose activity controls the colour changes are activated by nerve fibres which arise in the central nervous system of the animal, in lobes of the sub-oesophageal ganglia. It was pointed out some years ago [5] that the colour patterns of cephalopods are thus a visible representation of patterns of nervous activity.

In recent years J. Z. Young and B. B. Boycott

FIGURE 1 – *Cuttlefish. Side view of the head, with arms to the left. The animal is resting on a shell-gravel bottom, and showing the mottle pattern.* ($\times \frac{2}{3}$)

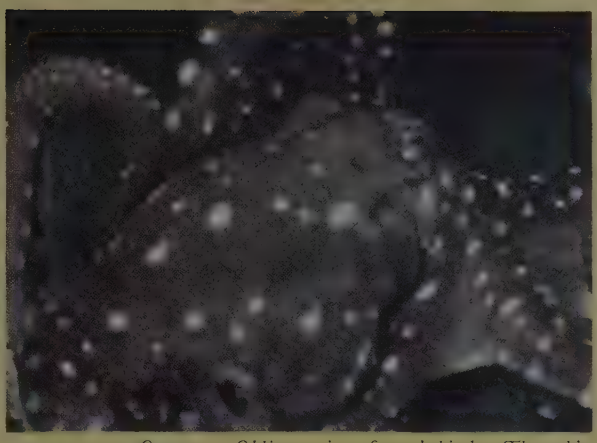

FIGURE 2 – *Octopus. Oblique view from behind. The white patches of iridocytes stand out against a uniform background.* ($\times \frac{1}{3}$)

FIGURE 3 – *Octopus. Oblique view from in front. The head and body show a mottle pattern.* ($\times \frac{1}{3}$)
*(Photograph by D. Wilson.)*

FIGURE 4 – *Cuttlefish. Side view. The animal has been disturbed, and the black-spot pattern is developing.* ($\times \frac{1}{4}$)
*(Photograph by D. Wilson.)*

FIGURE 5 – *Cuttlefish. Side view. The 'zebra' pattern.* ($\times \frac{1}{3}$)

*(Figures 1, 2, and 5 are from a ciné film on the Naples Zoological Station, made in 1952 by Dr O. Schulz-Kampfhenkel, who reserves all rights.)*

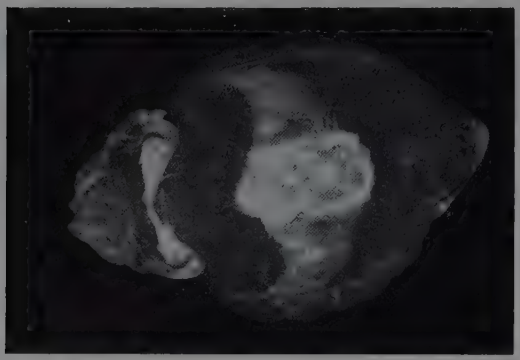

FIGURE 6 – *Cuttlefish. Dorsal view. White-square and stripe pattern.* ($\times \frac{1}{3}$)

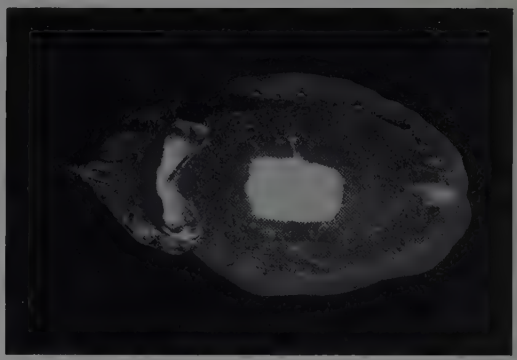

FIGURE 7 – *Cuttlefish. Dorsal view. The white-square pattern, with iridocytes elevated on papillae on the right side of the body at the base of the fin.* ($\times \frac{1}{3}$)

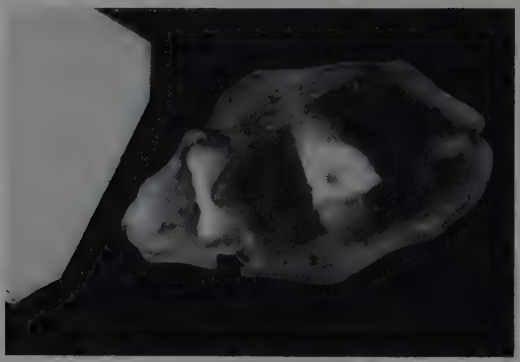

FIGURE 8 – *Cuttlefish. Dorsal view. The animal is lying on a black background with a white plate within sight, and the white-square and stripe pattern is developing.* ($\times \frac{1}{3}$)

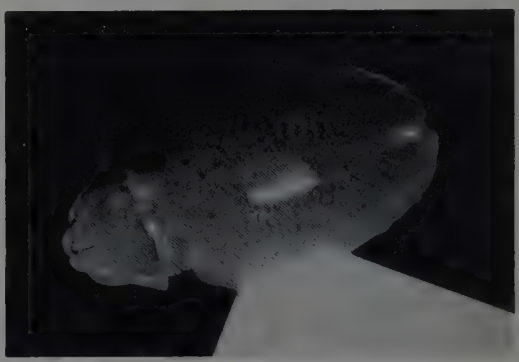

FIGURE 9 – *Cuttlefish. Dorsal view. The zebra pattern is fading and being replaced by the white-square pattern, which is developing first on the side of the body closest to the white plate.* ($\times \frac{1}{3}$)

have been considering this problem as a part of their studies of the behaviour of cephalopods and of the underlying nervous organization. In a preliminary report Boycott [2] gives an introduction to these studies. The chromatophore motor neurons in the sub-oesophageal ganglia are influenced by nerves arising in the supra-oesophageal ganglia, the 'higher centres' of the cephalopod, and these can be excited by fibres from the optic, tactile, and static sense organs. In the chromatophore lobes, the organization of the nervous tissue shows a significant difference between the octopus and cuttlefish and the squid. In the two former animals the mass of nerve fibres characteristic of nerve centres shows a greater regularity of arrangement. There is thus the exciting possibility that the colour changes of these animals may give a key to an extremely difficult general problem: that of correlating different kinds of organization in nervous tissue with differences in behaviour.

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# Chemical aspects of the atomic industry

E. GLUECKAUF

The importance of the roles of the physicist and the engineer in the atomic industry are generally understood, but the extent of the chemical effort involved is still too little appreciated. Nevertheless, it is a fact that plutonium production by means of natural uranium piles requires many more chemists than physicists and engineers together. Atomic power stations must be associated with vast chemical plants for the manufacture and recycling of the fissile materials and for the treatment and disposal of radioactive waste products.

The production of atomic power is based on the ability of certain unstable elements to react with neutrons and, in so doing, to set up a self-supporting chain reaction which can be controlled. The natural uranium pile utilizes this chain reaction, but as natural uranium, mostly uranium 238, contains only 0·7 per cent of uranium 235, the resulting energy is produced in a mass of material so unwieldy that it is difficult to utilize the energy released. To obtain atomic power more economically, we require not only nuclear fuel, but we require it in concentrated form. Such concentrated fuels do not occur naturally and they have to be manufactured by elaborate processes (figure 1). Fuels suitable for combustion with slow neutrons are potentially obtainable in three ways:

1. The isotopes of uranium can be separated and the 0·7 per cent of uranium 235 extracted.
2. Plutonium 239 can be 'bred' by making uranium 238 react with neutrons.
3. Uranium 233 can be 'bred' by making thorium 232 react with neutrons.

The first process seems, at first sight, the simplest, but it requires a high capital investment and consumes vast amounts of electric energy. The second process, which occurs in the natural uranium pile, proves to be the more economical method. The third process, which may well be the process of the future, because of the greater natural availability of thorium than of uranium, is not of interest at present, as it will work economically only with the surplus neutrons from concentrated-fuel reactors.

## PRODUCTION OF PLUTONIUM

The sequence of reactions in the natural uranium reactor is indicated in figure 2. A slow neutron meets a $U^{235}$ nucleus, combines with it to form an excited unstable atom, $U^{236}$, which immediately explodes into two fission fragments and two or three neutrons. On the average, 2·56 neutrons result. The fates of these neutrons are as follows:

1 carries on the chain reaction by combining with another $U^{235}$ atom.
0·9 combine with $U^{238}$ to produce, eventually, plutonium.
0·61 are lost in various ways: in the slowing-down process, as stable $U^{236}$, or by escaping.
0·05 are excess neutrons, which may be utilized either for speeding up the reaction or for making isotopes; if not so utilized they will have to be absorbed in the control rods.

Thus for every kilogram of $U^{235}$ destroyed we obtain 0·9 kg of Pu and 1 kg of fission products. These are contained in quantities of uranium of the order of tons, depending on the burn-up rate of $U^{235}$.

The fission products consist of thirty-five elements, ranging from zinc to gadolinium, i.e. drawn from the middle of the periodic system. Most of them are radioactive, 1 kg representing an original activity of the order of 2 million Curies.[1] This represents 10 kW of radiation power—enough to kill almost instantaneously any living cell exposed to it. It is, of course, this intense radioactivity that so greatly hampers chemical operations.

The chemical problems begin, however, long before a natural uranium pile can even be started. Figure 2 shows that only about 2 per cent of the created neutrons are excess neutrons; absence of these would prevent the pile being started up. If foreign neutron-absorbing materials were present in the pile, even in traces, they would soon raise the proportion of wasted neutrons from 0·61 to 0·66 or above, and so eliminate the excess neutrons required for accelerating the chain reaction. Consequently, all materials going into the making of a slow-neutron pile have to be chemically purified to a degree previously almost unheard of in industrial practice, and analytical methods had to be

[1] One Curie is the decomposition rate of 1 g of radium, or $3{\cdot}7 \times 10^{10}$ atomic decompositions per second. The unit of energy-release rate is the MeV-Curie, corresponding to $3{\cdot}7 \times 10^{10}$ MeV/sec, or 0·0054 watt.

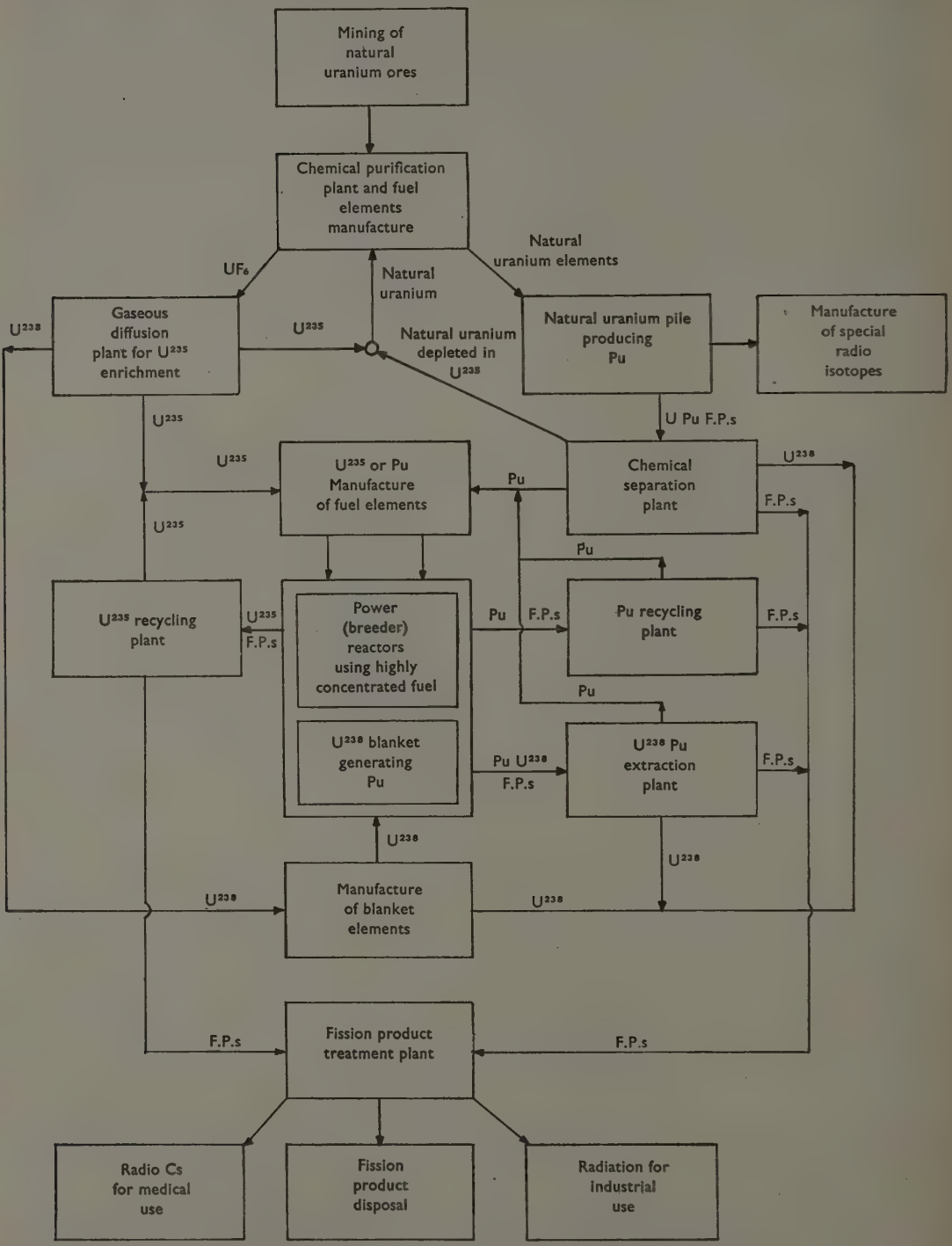


FIGURE 1 – *Diagram of chemical plants associated with an economic power reactor.*

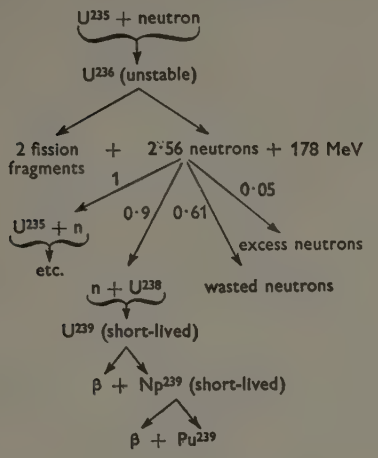


FIGURE 2 – *Fission scheme.*

developed for the determination of many impurities present to the extent of only a few parts per million. The small proportion of excess neutrons available in a natural uranium pile causes still further complications. Once the pile is running it produces its own poisons in the form of the fission products, some of which consume slow neutrons. Long before an appreciable fraction of the $U^{235}$ has been used up, these impurities begin to consume neutrons at such a rate that the reaction in the pile is no longer self-sustaining. It is, therefore, a feature of natural uranium piles, and of all slow-neutron reactors, that the fissile materials have to be regularly purified of their fission products.

### CHEMICAL SEPARATION DURING RECYCLING

The composition of the material that has to be dealt with is shown in Table I, which tabulates the quantities and the radiative intensities of the fission products several months after their removal from a pile. After this interval the more short-lived radioactive materials have already decayed, thus greatly simplifying the handling problem.

As there are present also iron, nickel, cobalt, and silicon as impurities, some 900 g of plutonium, about 1000 kg of uranium, and 1 or 2 g of americium, it will be seen that the mixture is quite a comprehensive one, deriving from all groups of the periodic table. Fortunately, the problem for the plant designer is not to separate the mixture into all its constituents, but to divide it, as sharply as possible, into three parts:

1. Plutonium for use as concentrated fissile material.

TABLE I

*Main fission products from 1000 g of $U^{235}$ (150 days irradiation, 30 days cooling)*

| *Group* | *Element* | *g.* | *Curies* |
|---|---|---|---|
| 1 | Rb | 14 | — |
| | Cs | 108 | 2 900 |
| 2 | Sr | 39 | 110 000 |
| | Ba | 39 | 66 000 |
| 3 | Y + rare earths | 308 | 675 000 |
| 4 | Zr | 114 | 119 000 |
| 5 | Nb | 5 | 200 000 |
| 6 | Mo | 84 | 190 |
| | Te | 14 | 1 200 |
| 7 | Tc | 26 | 170 |
| | I | 6 | 11 000 |
| 8 | Ru, Rh, Pd | 74 | 235 000 |
| | Kr + Xe | 128 | 6 300 |
| | Total activity: | | 1 426 760 |

2. Uranium for recovery and recycling.
3. The remainder, including all the active fission products.

Four principal methods of effecting this division immediately suggest themselves:

1. Solvent extraction.
2. The classical method of separation by precipitation from solutions.
3. Separation by high-temperature distillation of halides.
4. Separations using ion-exchange columns.

All these methods have their advantages and their disadvantages, but none of them can be as easily and as safely applied to continuous operation as solvent extraction, which lends itself readily to remote control. Since both uranium and plutonium nitrates are much more soluble than the nitrates of any other cations in water-insoluble organic solvents containing oxygen (such as ethers and esters), their separation from the bulk of the fission products by solvent extraction is practicable.

The chemistry of uranium and plutonium in these solvents is itself most interesting [1]. The nitrates are almost completely unionized. They are hydrated, on the average, with four water

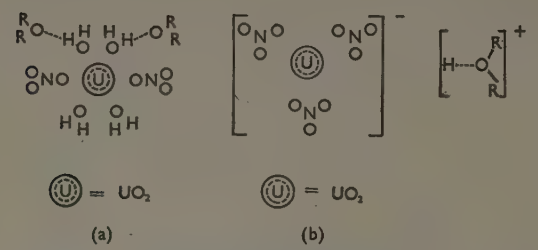


FIGURE 3*a* – *Model of undissociated uranyl nitrate in ether solution.* 3*b* – *Model of tri-nitrato-uranyl ion.*

molecules, which are carried into the organic solution, where further solvation with the organic solvent occurs. Thus uranyl nitrate, in a neutral ether solution, is roughly as shown in figure 3(*a*), where eight oxygen atoms surround each uranium atom. In the presence of strong nitric acid, however, the uranyl nitrate in the solution becomes partly ionized, forming an unhydrated trinitrato anion, $[UO_2(NO_3)_3]^-$, again with eight oxygen atoms around the uranium (figure 3(*b*)). Research has shown that the ability of solvents to extract uranium—or, more precisely, the free energy of the extraction equilibrium—is, for a given type of solvent, a simple function of the oxygen : carbon ratio of the solvent; it is almost independent of the molecular size or arrangement of the solvent molecules (figure 4).

As mentioned, the solvent extraction process depends upon the difference in the extractability of uranium and plutonium nitrates from that of all other nitrates. At the same time, uranium and plutonium differ greatly between themselves in the stability of their various valencies. Both can exist in the valencies 3, 4, 5, and 6, but the most stable valency of uranium is 6 (nitrate solvent-extractable), while the most stable valencies of plutonium are 4 (nitrate solvent-extractable) and 3 (nitrate not solvent-extractable). It is therefore possible, by the use of a reducing agent, to separate uranium and plutonium from each other by further solvent extraction.

Figure 5 shows a possible process of dissolving, extraction of uranium and plutonium in the oxidized state from fission products, separation of plutonium by aqueous extraction of the resulting organic solution under reducing conditions, and finally the extraction of the uranium back into water; at the same time the solvent is regenerated and goes back into the first column.

Chemical works in which such operations with radioactive materials are carried out are examples of extreme cleanliness. A working deck in the

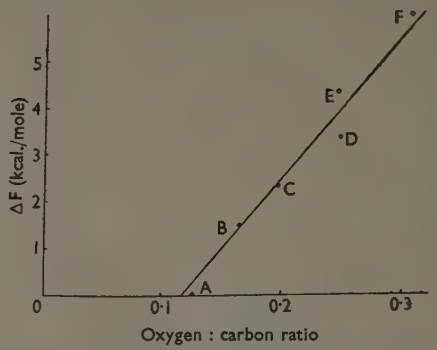


FIGURE 4 – *Free energy of solvent extraction of uranyl nitrate expressed as a function of the oxygen : carbon ratio of the ether.* $A$ = *n-dibutyl ether,* $B$ = *di-isopropyl ether,* $C$ = *di-butyl cellusolve* $[C_4H_9—O—C_2H_4—O—C_4H_9]$, $D$ = *di-ethyl ether,* $E$ = *di-butyl carbitol* $[C_4H_9—O—C_2H_4—O—C_2H_4—O—C_4H_9]$, $F$ = *penta-ether* $[C_4H_9—O—(C_2H_4—O—)_4C_4H_9]$.

tower of the primary separation plant at Windscale is remarkable for the absence of any spectacular apparatus. Only a few valves, flow indicators, and pressure gauges are seen outside the thick concrete wall. Inside this cell, which has not been entered since the factory began operating several years ago, there are no pumps, no valves, no movable parts; only extraction columns, tanks, and miles of stainless steel piping, in which the flow of the liquids is controlled by air-pressure and gravity, using the simplest possible devices. Figure 6 shows the separation plant with its 65-metre extraction tower. Its massiveness can be judged by the fact that it took 30 000 tons of concrete to build it. Chemical processing does not, of course, stop with the primary separation. Both the uranium and the plutonium have to be further purified; after removal of the radioactive fission products, however, this can be done by essentially conventional processes.

Extensive ancillary laboratories are, of course, necessary for the strict control of these processes. A principal difference between these and the research laboratories of other chemical industries is the predominance of ventilation equipment. Radioactive dust is an even greater health hazard than radiation is, and as many as sixty air-changes per hour may be required in laboratories handling plutonium; both radiation monitors and dust-activity monitors are a prominent feature of these laboratories. Under the prescribed conditions work is absolutely safe, and the permitted tolerance of radiation is in fact less than that produced by wrist watches having luminous dials containing small amounts of radioactive material.

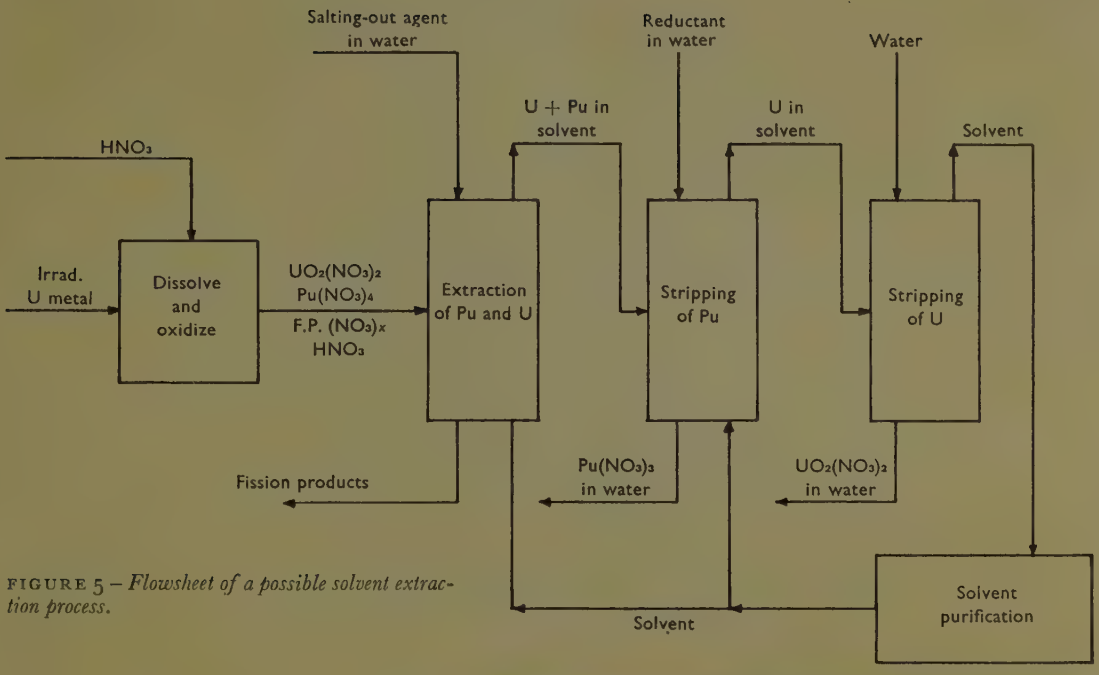


FIGURE 5 – *Flowsheet of a possible solvent extraction process.*

FIGURE 6 (*right*) – *External view of Windscale separation plant. In the background can be seen the stacks of the production piles, with their filters at the top.*

FIGURE 7 – *Chemical engineering tower at Harwell.*

FIGURE 8 – *Handling of radioactive chemicals behind a lead wall.*

DISPOSAL OF FISSION PRODUCTS

Like other industries, the atomic industry has the problem of disposing of its waste products, but in this case they are more toxic and dangerous than in most others. The activities are too long-lived, and too intense, for the waste involved to be thrown into the sea. Even if mixed with concrete and sunk off the Atlantic shelf, the danger to fish —and so to human health—is not sufficiently predictable to permit such an irretrievable step. At present, however, the quantities are not so large as to prevent permanent storage in stainless steel tanks, although this is expensive. For the moment, therefore, the disposal problem is not a serious one.

The situation will, however, be very different when a serious programme of atomic power production begins.[1] Britain's National Coal Board [2] has expressed the opinion that the amount of coal available in 1965 for generation of electricity will be of the order of 50 million tons (see figure 9). The British Electricity Authority, on the other hand [3], expects to need to increase its coal consumption at a rate which by 1965 would bring it up to 65 million tons annually. It seems that only atomic energy can bridge this anticipated gap. To produce energy from atomic sources at the necessary rate would require the building of about fifty reactors by 1970, consuming altogether about eight tons of nuclear fuel annually, and producing an equal amount of fission products. In terms of activity this means production of about 1000 million MeV-Curies, even allowing for one year's decay. This is equivalent to the radiation from 200 tons of radium.

When working on this scale disposal of fission products is bound to become a serious problem. A high degree of chemical concentration would obviously be necessary before the fission products could be stored economically. In order to do this, the hundreds of times larger quantity of chemicals which have been added during the primary separation process would have to be separated. These problems are now being actively investigated at Harwell by both physical chemists and chemical engineers; parallel investigations are proceeding in the United States [4].

Many suggestions for methods of dealing with the waste have been made, and two general tendencies can be discerned. The first is to bury the fission products, or their solutions, on land, under conditions such that they could not possibly return to the surface until their radioactivity had completely decayed. The second is to reduce the products to minimal bulk, in a form not easily dissipated, and to keep them under permanent control. Whatever method is accepted, the cost of the disposal process must not, for economic reasons, affect the cost of the electricity by more than a very small fraction of a penny per kW-hour of electricity produced. This might represent about 5 per cent of the cost of production, ignoring distribution and overhead expenses, which amount to several times the cost of fuel. Such considerations considerably restrict the methods which might be employed, and virtually eliminate any involving transport of the fission products over long distances. In the choice of sites for atomic factories waste disposal has always been important, and it is likely to become still more so as the quantities of the waste increase.

At the moment it appears that, whatever the method of final disposal, three chemical processes are likely to have to be undertaken:

1. Concentration of the waste solutions, presumably by removal of the bulk of volatile inactive constituents by evaporation.
2. De-acidification of the greatly reduced solution volumes, by acid extraction, electrolysis utilizing anion-exchange membranes, or neutralization.
3. Separation of fission products into long-lived products of more than five years half-life, and shorter-lived elements.

The first two processes offer obvious advantages for storage of any type. The third would permit us to accept for the shorter-lived materials the slight, but finite, risk connected with direct disposal in the ground; within twenty years their activity would have become insignificant. As this method is, on suitable sites, very inexpensive, it

[1] See 'A Programme of Nuclear Power' (Her Majesty's Stationery Office, 1955), published as we go to press.

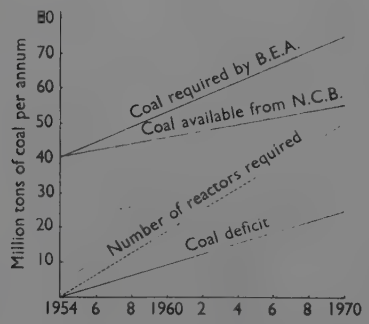


FIGURE 9 – *Predicted coal deficit in Britain and number of reactors required to cover it.*

would permit greater expenditure on the disposal of the smaller bulk of really dangerous, long-lived materials, such as $Cs^{137}$ and $Sr^{90}$; these would most probably have to be permanently controlled.

### UTILIZATION OF FISSION PRODUCTS IN THE FUTURE

At the moment it is the nuisance value of the fission products which demands detailed consideration, but there is no reason why this should always be so. $10^9$ MeV-Curies of fission products represent a unique radiation source of great potential chemical activity, with an uninterrupted supply of 5400 kW. Today we know little about how such intense radiation sources could be economically used in chemical reactions, but even as a source of heat—reckoned at 1d. per kW-hour—the annual value is about £200,000. As a radiation source the potential value must be many millions of pounds annually. It is obvious that such a source of energy cannot be disposed of as mere waste, and investigations are proceeding to develop methods of utilizing these radiations [5] in large-scale industrial processes. Among suggested uses are those of initiating and speeding up chain reactions, like the polymerization of ethylene and the cross-linking of long-chain polymers. Other fields where the use of radiation on a large scale is contemplated are the preservation of certain foods and the sterilization of pharmaceutical products. Other profitable industrial uses may well be discovered by the time really large quantities of fission products become available.

Most of the radiant energy of the processed fission products is contained in four elements, which have greatly differing properties. There are the long-lived isotopes of caesium (half-life 32 years, emitting valuable γ-radiation), and of strontium (half-life 20 years, emitting pure β-radiation). The former is bound to contribute greatly towards the expansion of radiotherapy in cancer treatment, though this field alone will require only a minute fraction of the caesium produced. Then there are the shorter-lived isotopes, $Zr^{95}$ (with its daughter Nb), and $Ce^{144}$ (with its daughter Pr). The former emits an intense γ-radiation which, for a given weight, is about 100 times more intense than that of caesium, and it may find useful applications when small γ-sources of an intensity of about one million Curies are required. $Ce^{144}$ emits a not quite pure β-radiation, and on account of its shorter half-life has a much higher specific β-intensity than has $Sr^{90}$.

It is not generally realized that the fission products contain also a number of inactive chemical species which are of considerable value, even though this value is dwarfed by that of the reactor energy and even by that of the radiant energy of the fission products. Among these inactive products the most valuable is xenon, which, on the basis of eight tons of fissile material, would be produced at the rate of 100 $m^3$ per year. The present price of this gas is £12 10s. per litre. It is, of course, difficult to predict the future price of chemicals which at the moment are very rare and for which there is little or no demand. Other valuable inactive products, calculated on the same basis, will be:

| | *kg/year* | *Present price of commercial products* |
|---|---|---|
| Ru .. | 350 | £300/kg |
| Rh .. | 130 | £600/kg |
| Pd .. | 60 | £300/kg |

An interesting product, which does not exist at all in nature, is element 43, technetium. This would be produced at the rate of 200 kg/year. Its radioactivity, it has a half-life of $2 \times 10^5$ years, is virtually negligible, and useful applications for this element may be discovered. It is, of course, too early to say whether the cost of processing will permit an economic recovery of these materials from highly active mixtures, but it may well be that the possibility of recovery at a later date will be taken into account when selecting methods of disposal.

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# Some early English instrument makers

DEREK J. PRICE

In the early days of science the instrument makers, generally as a group but sometimes individually, played an important role, and nowhere more so than in Britain, where their craft flourished exceedingly. Informal meetings in and near the shops of instrument makers provided an opportunity for the exchange of ideas before the organization of some of the early scientific societies. Their instruments advanced science, especially astronomy and navigation, and many are exceptionally fine examples of the craftsmanship of their day.

The earliest years of the Scientific Renaissance, in the sixteenth and seventeenth centuries, were marked by an enormous increase in the number of 'little men of science.' Great men there certainly were too; but in 1500 they were isolated scholars, whereas by 1700 they were at the centre of a considerable group of people who made and sold scientific devices or who bought and used such devices in the course of their daily work.

The instrument makers and engravers, the teachers of navigation, the surveyors and other mathematical practitioners, were for the most part obscure people. Many of their instruments survive, however, some having been preserved as examples of the finest craft of the metalworker. A few of their manuscripts and books survive too, but in general we know little of the lives and the everyday work of these men. Yet their workshops, their trade guilds, and the places in which they met, were the first instances of organized activity in science outside the universities. At first they were artisans employed by the mathematicians and astronomers to make instruments more complicated, more accurate, or more lavish than they themselves could make unaided. Later, however, the instrument makers themselves acted as a centre, and attracted a clientele of scholars and professional practitioners as well as amateurs of science who were excited by 'the new philosophy.' Still later, groups of these scholars, practitioners, and amateurs formed the basis of the *Accademia del Cimento* at Florence, the *Académie des Sciences* at Paris, the Royal Society of London, and the other national academies which are customarily regarded as the concomitant of modern organized scientific inquiry.

Nowhere was the role of the instrument maker more important than in England. The craft had started in Nuremberg late in the fifteenth century, probably under the inspiration of Regiomontanus, the 'father of modern astronomy.' By the middle of the sixteenth century it had spread to Augsburg and other towns in Germany. Thence it came to Louvain and, with a quickening of the pace, instrument makers began to flourish all over Europe. England made a comparatively late entry into this field, but when it came the craft took root firmly in the metropolitan and maritime centre of London, and it increased prodigiously. Elsewhere in Europe the situation was not so favourable. In Italy and in France there were a number of fine craftsmen, but no active school of instrument-making developed; in Louvain the workshops were overrun and dispersed during the invasion by Alexander Farnese in 1578; in Germany the craft became moribund soon after 1600 and declined until it was almost extinguished by the Thirty Years War. By 1650 London had become the greatest European centre for the manufacture of scientific instruments, and other countries were beginning to be concerned about their lack of comparable craftsmen and facilities. London, however, had established such a lead that it was able to maintain its position until the dying out of the old school of instrument craftsmen as a consequence of the new era of factories and mass-production.

The question of who was the first English instrument maker is largely one of definition and in consequence is very difficult to answer. In the widest sense, the first tools used by primitive man were scientific instruments and the earliest shadow-measurement involved the making of a sundial. Again, up to the end of the Middle Ages scientists designed and made their own instruments; the remarkable work of the astronomers at Merton College, Oxford, in the thirteenth and fourteenth centuries led to the making of many new and complicated devices.

Probably the first important contact between England and the new but flourishing German schools of instrument-making came through the

Bavarian, Nicolas Kratzer (1486–1550), who was appointed a tutor in the household of Sir Thomas More, and later as astronomer- and horologer-royal to Henry VIII and as a lecturer at Oxford. He is well known through a portrait of him, now in the Louvre, by his friend Holbein (see figure 3). Some of Kratzer's instruments shown in this portrait are also to be seen in the painting by the same artist of 'The Ambassadors,' now in the National Gallery, London (figure 5). While at Oxford he taught the 'Doctrine of the Sphere' and constructed elaborate sundials; one of his dials, made for Cardinal Wolsey, is preserved in the Museum for the History of Science, Oxford.

Kratzer may be regarded as an astronomer rather than as an artisan. If he awakened interest in instruments, he seems to have done little or nothing to train others to make them; perhaps this arose in part from the fact that he never mastered the English language.

The second contact with the European schools was more productive. This time it was made by a Protestant refugee from Flanders, who came to London from a village near Liège and changed his name from Thomas Lambrit to Thomas Gemini (fl. 1524–62). He was a skilled engraver by trade, and seems to have established a reputation by engraving the plates for the English edition (1545) of the 'Anatomy' of Vesalius. Gemini seems to have had some contact with the Arsenius family, instrument makers in Louvain, who ran a workshop which had been started by their relative, the astronomer Gemma Frisius, and his collaborator, Gerard Mercator. Three fine astrolabes by Gemini that have been preserved are executed in a style very similar to that of Arsenius; one of them was made for Sir John Cheke, and is now at the Royal Observatory of Belgium, and the two others for Queen Elizabeth; one of the latter is at Oxford and the other at the National Maritime Museum, Greenwich. Besides making instruments, Gemini engraved maps and published books, among them Leonard Digges's 'Prognostication' and 'Tectonicon,' which describe many new types of instruments.

The first native Englishman to make fine instruments was undoubtedly Humphrey Cole (1530?–91), a north-countryman whose chief employment was as an engraver and die-sinker, assisting William Humfrey at the Royal Mint. He also worked as an engraver for the printer William Jugge and as a technician for the Mineral and Battery Works, which established brass-founding in England on a firm footing. Cole's work is in some respects very similar to that of Gemini; this supports the suggestion that as a young man he might have learned his art as apprentice to Gemini, then the only instrument maker resident in London. He may also have been related to Jacob Cole, who lived in London and was a brother-in-law of Abraham Ortelius, the famous Antwerp geographer. If this were so it would establish yet another link with the Low Countries.

As regards quality of workmanship and engraving Cole is second to none, and the range of instruments which survive shows that he was able to turn his hand to everything. There are astrolabes and all sorts of sundials, theodolites and gunners' compasses, a mariners' astrolabe, a nocturnal, an armillary sphere, compendiums which contain almost a miniature observatory (including one made for Sir Francis Drake and another for his printer friend, Jugge), and the complete instrumental equipment for Martin Frobisher's first voyage in search of the North-west Passage. He was certainly a great master of his craft; nevertheless we know from petitions and the few contemporary references that he was destitute in his old age and died a poor man.

Even within Cole's lifetime the number of instrument makers in London had begun to multiply. A contemporary advertisement[1] reminds the reader that 'Scales, compasses, and sundry sorts of Geometricall instruments on metall, are to be had in the house of Humfrey Cole, neere unto the Northe dore of Paules, and at the house of John Bull at the Exchange Gate: in wood, at John Reades in Hosier Lane, at James Lockersons dwelling neere the Conduite at Dowe gate, and at John Reynolds at Tower Hill. . . . I have thought good to give advertisement hereof, because many that would provide such things, knowe not where to have them.'

In addition to these men there are two whose names are sometimes mentioned with Cole's, and whose style of work and design of instruments indicate that they were probably apprenticed to Cole, or at least trained by him. Both men, James Kynfin (fl. 1569–1610) and Charles Whitwell (fl. 1591–1606), made many instruments for Sir Robert Dudley (figure 2). A number of signed instruments are still preserved in Florence, where Dudley lived in exile. Kynfin made also a fine pocket dial for Robert Devereux, Earl of Essex, and in a letter dated 1609 he describes himself as

[1] Edward Worsop, *A Discoverie of sundrie errours and faults daily committed by Lande-meaters ignorant of Arithmetike and Geometrie.* London, 1582.

FIGURE 1 – *The two-foot astrolabe of Humphrey Cole.* (Reproduced by courtesy of the Society of Antiquaries of London.)

FIGURE 2 – *Azimuth dial invented by Sir Robert Dudley, probably made by Whitwell or Kynsin. It is a precursor of William Oughtred's 'double horizontal dial.'* (Reproduced by courtesy of the Trustees of the British Museum.)

FIGURE 3 – *Holbein's portrait of Nicolas Kratzer.* (By courtesy of the Louvre, Paris.)

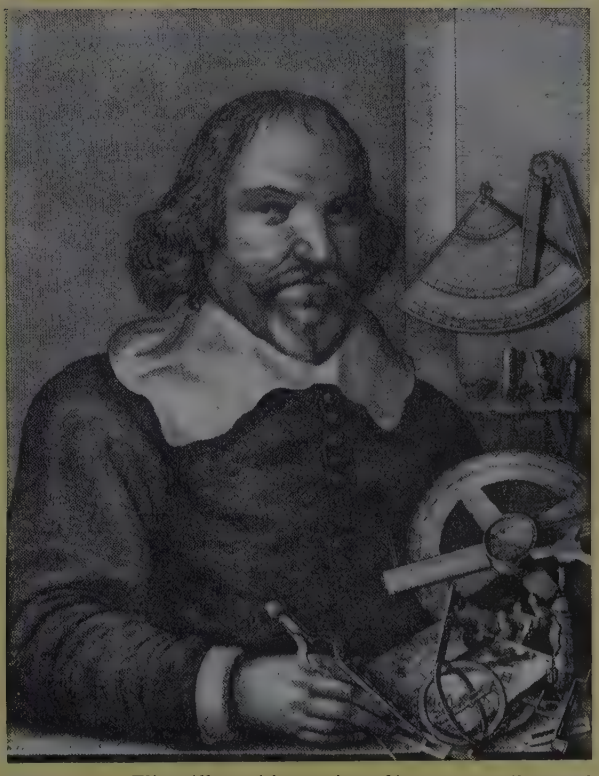

FIGURE 4 – *Elias Allen, with a variety of instruments. Engraved by Hollar from a painting (now lost) by H. Van der Borcht.* (Reproduced by courtesy of the Director of the Science Museum, South Kensington.)

FIGURE 5 – *Detail of 'The Ambassadors' by Holbein, showing globe and a variety of measuring instruments.* (Reproduced by courtesy of the Trustees of the National Gallery, London.)

a servant to Prince Henry and says he has worked for forty years on certain 'engines of war.' About Whitwell we know almost nothing apart from his signed instruments and the fact that his address was later used by the doyen of English instrument makers, Elias Allen (fl. 1606–54), who may therefore have been his successor and perhaps his apprentice.

Almost uniquely among such artisans, Allen attained sufficient importance for his portrait, a very fine one, to have been preserved. It is reproduced here as figure 4. It was painted by H. Van der Borcht and engraved by Wenceslaus Hollar in 1660, six years after Allen's death. It shows him as a stocky man with beard, moustache, and straggly hair, with a bench full of unfinished instruments before him and others hanging on the wall. He was born near Tonbridge, Kent, probably in the village of Ashurst, where he lies buried; a dial presented by him is still preserved in the churchyard there. As a young man he undertook estate surveys (e.g. in Oxfordshire in 1609), but he was well established in London by 1611. From about 1630 onward, mentions of him and signed and dated examples of his work become very frequent, and in 1636 he was elected Master of the Clockmakers' Company, being the first instrument maker to hold that office. His shop, at the sign of the Horse Shoe, 'near Essex Gate, over against St Clement's Church, Strand, outside Temple Bar,' was known and commended by practitioners, writers, and amateurs of science.

Allen occupied some sort of official position in the rapidly increasing community of instrument makers. It was he who made the facsimile of the brass standard yard at the Guildhall, and it is he who is named by Robert Hooke as the chief of 'the club of instrument makers,' an organization about which, unfortunately, nothing else seems to be known. One supposes that the mathematicians, surveyors, navigators, and amateurs of the day would have found the instrument makers' shops—where they commissioned work for themselves and their patrons—and the neighbouring taverns (and later coffee houses) useful places for the exchange of ideas and for informal discussion of new discoveries. It was clearly to the instrument makers' advantage to foster the experimental interests of their customers. By 1650 there must have been at least thirty instrument makers working in London; after the turn of the century there was a sudden increase in interest which made their numbers grow faster than ever before. The average rate of publication of books on 'practical mathematics' jumped from about two a year before 1650 to nearly seven a year after. This was the same ferment of activity which, a decade later, led to the formal foundation of the Royal Society.

With such a large population of instrument makers it is almost impossible to trace all the successions of masters and apprentices. In the case of Elias Allen we know that his son or nephew John Allen (fl. 1632–7), was taken into the business. In addition he had an apprentice, Ralph Greatorex (1625–1712)—John Aubrey gives him the title Captain—who, like his master, was the personal friend and correspondent of William Oughtred, the mathematician, who designed many instruments. Greatorex worked for many of the early members of the Royal Society, including the diarist Samuel Pepys, who often mentions him.

From Greatorex the line extends to his apprentice, Henry Wynne (fl. 1654–1709), and in turn to Wynne's apprentice, Thomas Tuttell (fl. 1695–1702), both of them well known from fine examples of their work. There, after six generations, one loses trace of that particular branch, but by that time there are many others, and it seems pointless to attempt to trace them all back to Gemini or Cole. Throughout this period it is no dead tradition that is being handed down from master to apprentice. All the time there were new types of instrument being designed and new techniques and materials being used in their construction. Some of the instrument makers started to construct optical devices such as microscopes and telescopes, though this work was later claimed as the prerogative of members of the Spectaclemakers Company—more general craftsmen had followed the lead of Elias Allen by joining the Clockmakers Company *en bloc* in 1667.

Gradually, towards the end of the seventeenth century, a slow change becomes apparent in the style and execution of the instruments. Ornamentation and beautiful engraving tend to disappear on all but 'presentation models' and it is replaced by the more impersonal and functional utilitarianism of modern instruments. The art of the instrument maker was being superseded by a large-scale industry, and meetings of the Royal Society and other organizations had taken over the functions of the informal discussions.

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# Crustacean colour change and neurosecretion

SIR FRANCIS KNOWLES

Some of the colour changes which crustaceans make in response to stimuli, such as illumination and shade of background, have long been known, but it is only comparatively recently that the underlying mechanisms have begun to be understood. Research has shown that crustaceans have a complex neurosecretory system, and it seems that part of this has evolved in response to a need for fast, yet maintained, control of the colour changes.

Each day and night all living things make many delicate and precise adjustments to their changing environments, and nowhere is this more evident than in the elaborate colour-changes of crustaceans. Some of these, slow, regular and predictable, are synchronized with the movements of the Sun, the Moon, and the Earth, with dawn and nightfall, the tides and the seasons; others are adaptive responses to illumination and background.

During the past few years Brown and his collaborators have carried out detailed investigations on the fiddler crab (Uca) which show that the overall colour of this animal alters rhythmically. The interval between lightening and darkening is regulated by the interaction of two rhythms—a diurnal one and a tidal one. The crabs darken during the day and become pale at night, but the moment of maximum darkening in any individual is synchronized with the time of low tide on the beach where the animals live; consequently it moves forward each day as the time of low tide advances. Both these rhythms are persistent and will continue even if the animals are brought into the laboratory and kept in permanent darkness. Even if the environment is kept constant the crabs continue, in darkness, to change colour in harmony with their late companions on the beach. When those on the beach are taking on their darkest hue as a protection against sunlight and predators as the sun rises and the tide recedes, their captured comrades, who may have been kept in darkness for as long as a month, are also becoming their darkest. The crabs seem to have within them a biological clock which shows a most remarkable resistance to temperature change. Altering the temperature between 6° and 26° C did not alter the diurnal or tidal rhythms, though these could be changed by exposing the animals to unusual periods of illumination. These experiments and their implications have recently been summarized by Brown [1].

It is possible that these rhythms of Uca are characteristic of crustaceans as a whole, but the more dramatic and complex colour changes of crustaceans are those which are associated with sudden and irregular changes of background and illumination as the animal moves among sand, rocks, and weeds. Study of the adaptive colour changes that cause the shade and the pattern of the animal to match the background has revealed a remarkable neurosecretory system of control having many features of general biological interest.

## CRUSTACEAN COLOUR

It is little more than a hundred years since colour change in crustaceans was first recorded, though colour changes in the lower vertebrates have attracted the attention of naturalists since the earliest times. The colours of crabs, shrimps, or prawns at first sight seem to be dull when compared with the brilliant colours of some fishes and reptiles, but under the microscope the dull overall colour can be seen to be the result of an interplay of brilliant pigments of many colours, contained in delicately branched chromatophores (plate I). Independent movements of these pigments result in a very close matching of the body colour of the animal with the background on which it rests.

Although the different states of a chromatophore are described as 'expansion' or 'contraction', it is generally accepted that the fine processes of a chromatophore are fixed in position in the hypodermis and that the colour changes are brought about by the movements of the pigment granules along fixed pathways, possibly by streaming movements of the cytoplasm. Many chromatophores are syncytial structures containing more than one pigment.

Crustacean colours and patterns are very diverse, yet in any one species the chromatophore organization is remarkably constant; many different types of chromatophore, each with a specific distribution, form a definite pattern. For example, in the common prawn, *Leander serratus*, which has been used for much experimental work on crustacean colour, the pattern is largely due to large red-yellow chromatophores, which are arranged in bands, and red-white light-reflecting chromatophores, which are sparsely but regularly distributed and are very noticeable when the prawn is on a dark background. The rest of the body is covered with relatively small red-yellow chromatophores. Red, yellow, and white chromatophores are also found on the legs and on the telson and uropods, but these peripheral chromatophores do not always change in phase with those of the body; although they closely resemble the body chromatophores, they are evidently physiologically different.

If prawns are placed in a white dish and are illuminated from above, the white chromatophores expand but the dark chromatophores contract. Conversely, on an illuminated black background, the dark chromatophores expand but the white ones contract. In their natural surroundings however, prawns seldom meet such intense illumination or such monochromatic backgrounds as those encountered in laboratory experiments. Prawns taken from a dredge which has brought them to the surface, and examined at once, show every possible variation in the degree of dispersal of the different chromatophore pigments. So intricate a system must clearly have a complex mechanism of control; for many years nervous control was suspected, even though the most diligent search for nerve endings in chromatophores had failed to reveal them.

### THE DISCOVERY OF THE SINUS-GLAND

Crustacean endocrinology may be said to have begun with the independent demonstration by Perkins (1928) and Koller (1928), working with the shrimps Palaemonetes and Crangon, that interruption of the blood supply to the chromatophores brought about an immediate immobility of the pigments, but that nearby nerve transection was without effect [2, 3]. Chromatophores in denervated areas continued to change when the illumination or background colour was changed. In their search for a blood-borne substance affecting pigment movements they found that by removing the eyes and their stalks they produced dark shrimps with dispersed red pigments; the normal pale colour could be restored if sea-water extracts of the eye-stalk were injected into the eyeless animals. Some years later Hanström [4] showed that the most potent source of pigment-activating substances in the eye-stalk was a small, richly innervated, disc-shaped structure; this he had previously described and called the blood- or sinus-gland, because of its proximity to a blood sinus. For many years following its discovery investigators sought keenly to determine the structure of the sinus-gland, but surprisingly little progress was made. It did not appear to be cellular, though scattered cells have been seen in the sinus-glands of some species [5]. No clear ducts were found, yet lines having the appearance of fine channels were sometimes observed. All investigators agreed that the structure was an extremely simple one, which seemed all the more remarkable when later studies showed that the sinus-glands were apparently concerned in the control of many activities, among them the movements of two retinal pigments, moulting, growth and maturation of the eggs, and the level of blood-sugar. It seemed pertinent to ask: does the sinus-gland produce all the substances which it has been shown to contain, or are these made elsewhere and merely stored in the sinus-gland?

### HORMONES IN THE CENTRAL NERVOUS SYSTEM

While the researches of Hanström were establishing that the sinus-gland was a most potent source of pigment-activating hormone, it had become clear that pigment-activating hormones were also being produced elsewhere. In 1933 Brown [6] found that extracts of the central nervous system contained pigment activators. In 1939 Knowles [7] showed that a white-pigment activator could be extracted from the thoracic region of the central nervous system even when the eye-stalks and their contained sinus-glands had been removed three or four weeks previously. The subsequent search for pigment-activating substances has been described by Brown [8]. Attempts to localize the pigment-activating centre of the nervous system showed that a great activity lies in a transverse commissure, the tritocerebral commissure, so called because of its close phylogenetic relationship with the brain. A closer study of this region showed that a great activity lay not in the commissure itself but in two nerves which arise from the commissure and terminate in muscles near by [Knowles 9, 10]. In

the prawn Penaeus each nerve is swollen before it reaches the muscle, forming a flat plate which lies alongside a blood-sinus; extracts of this plate were found to have an extremely high pigment-activating potency. Each plate contained a network of fine nerve endings, which apparently did not innervate any end-organ. It seemed reasonable to suggest that they were involved in the liberation of pigment-activating hormones into the adjacent blood-sinuses, and that they might contain these substances as well as control their release. This, the first combined physiological and anatomical demonstration of a neurohumoral system in crustaceans, was soon followed by parallel work on the sinus-gland and other organs.

Many workers studying a moult-inhibiting hormone in crustaceans had reported that the removal of the eye-stalks accelerated moulting changes, but that removal of the sinus-glands alone did not. In 1951 a number of papers were published, all indicating that some of the sinus-gland hormones were not produced in this body but in a cluster of cells previously named the X-organ, and that the substances made in the X-organ cells passed along axon fibres to the sinus-gland. Enami [11], and later Bliss and Welsh [12], showed that the sinus-gland of some crabs was in fact little, if anything, more than the swollen terminations of nerve fibres which originated in the cell-bodies of the X-organ, and that the sinus-gland/X-organ complex was a neurosecretory system bearing certain resemblances to the hypothalamus-pituitary system in chordates. With this discovery a new era in crustacean endocrinology began, and at present a great deal of work is being directed towards the unravelling of the very complex neurosecretory system which undoubtedly exists in crustaceans.

Alexandrowicz has described a number of neuropil-like meshworks of nerve terminations in close proximity to blood-sinuses, and it has been shown that some of these contain physiologically active substances affecting the rate of heart-beat [13, 14]. At present, however, the only structures known to release pigment-activating hormones are the sinus-glands and the post-commissure organs, and the effects of injections of total extracts of these organs suggest that the substances which they contain differ significantly. The injection of sinus-gland extract into an eyeless prawn is followed by a concentration of the small red chromatophores of both the body and the tail. The large red chromatophores are also concentrated, though to a lesser degree, but the white chromatophores are generally unaffected. On the other hand, injection of extract of the post-commissure organs brings about a maximal concentration of the large red chromatophores; little or no concentration of the small red chromatophores; a concentration of the whites; and a maximal dispersal of the red pigments in the tail chromatophores. The differences in the effects of injection of these extracts are very striking (plate II). One produces an almost transparent prawn in which pattern is maximally displayed: the other produces a dark, uniformly coloured animal.

### THE NUMBER OF CHROMACTIVATING HORMONES

Early experiments on different backgrounds showed that the various crustacean pigments have an independence of movement best explained on the basis of the existence of many hormones, each affecting movement of one pigment. It was, however, suggested that the diverse pigment movements might be explained on the basis of the existence of one or a few hormones, supposing that various pigments might be susceptible to the same hormone but that the actual effect depended on the concentration of the hormone in the blood; alternatively, a few hormones might, by being present in various combinations, produce multiple effects. A final decision between the unitary and the multiple hormone theories had to await the separation of different substances each having specific effects on different pigments. Owing to our scanty knowledge of the chemistry of these hormones and the difficulty of obtaining sufficient quantities for analysis, this separation was difficult to effect.

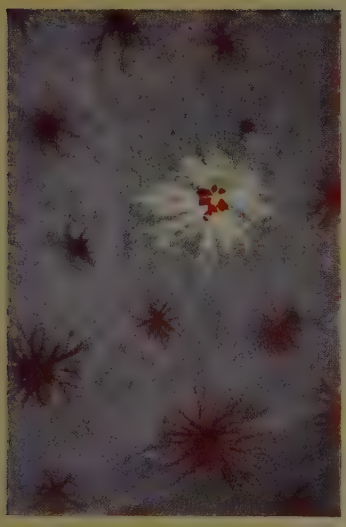
Comparison of the effects of injecting sinus-gland and post-commissure organ extracts suggests that there may be many hormones, and the experiments of Brown and Klotz [15] have shown that by extraction with alcohol two substances from the commissure of Crago can be almost completely separated. One, soluble in alcohol, concentrates body chromatophores but does not affect those of the tail. The other, insoluble in alcohol, darkens both the body and the tail. These and other experiments give reason for believing that more than one hormone affects pigment movements in crustaceans, and that some substances disperse chromatophore pigments and that others concentrate them. This concept of humoral action in crustacean colour change has been supported by recent separation experiments, using paper chromatography and paper electrophoresis, on which the writer and his collaborators are at present engaged [16].

In a typical paper-electrophoresis experiment sinus-glands or post-commissure organs were extracted with water and the resulting solution was applied to the centre of a paper strip. After electrophoresis the paper was dried and then cut into a number of sections; each portion was extracted with sea-water and the extract was injected into eyeless animals. The resultant colour changes gave an indication of the presence of pigment-activating hormones at various points along the paper strip and showed that the separation of different substances, with specific effects, was possible (figure 18). For example, post-commissure organ extracts have yielded after electrophoresis at *p*H 7·8 (*a*) an electropositive 'A' substance which concentrated all chromatophore pigments; (*b*) an electronegative 'B' substance which concentrated white pigments and the red and yellow pigments of the large red chromatophores, but which expanded other chromatophores of the body and the tail; and (*c*) more mobile substances, each specific for one pigment type. The 'B' substance seemed to be antagonistic to the 'A', and total extracts of the post-commissure organs had predominantly the 'A' or the 'B' effect.

It is by no means certain that all the substances which we have separated by electrophoresis are in fact functional hormones normally present in the blood stream. Indeed, some evidence suggests that the crude extraction methods adopted by earlier workers may have brought into solution substances present in the neurosecretory organs, which when injected had an effect on pigment movements, but which might not under normal conditions have been liberated into the circulation. For example, we have found that extracts of the sinus-glands and post-commissure organs of crustaceans, and of the corpora cardiaca of insects, contain the 'A' substance, active for more than one pigment, which is evidently of relatively high molecular weight. The organ-extracts tested contain a great deal of this substance, and it is tempting to regard it as a functional pigment-activating hormone. Yet if we lay the post-commissure organs in water and electrically stimulate them, we do not afterwards find this substance in the water, though other pigment-activating substances are present. The 'A' substance and the 'B' substance will not pass through a Cellophane membrane, through which other pigment-activating substances, present in total extracts, will pass (figures 19, 21, and 22). Our electrophoresis methods have also revealed mobile substances, each affecting a single pigment, some distance from the point of application to the paper strip, and it seems possible that these are in fact the active blood hormones and that the less mobile substances, with multiple effects on the chromatophore system, may be precursors. It is interesting to note that extracts of the posterior pituitary lobe in mammals, also considered to be a neurosecretory organ, have been shown to contain peptides of relatively low molecular weight having either oxytocic or pressor effects, but not both, and also a protein complex having both pressor and oxytocic activity. It has been suggested that the protein complex is a 'mother-molecule' of the lighter active substances present [17]. Our experiments indicate a similar possibility in the pigment-activating hormone systems of crustaceans.

The possibility that precursor substances are present in the cell-bodies of a neurosecretory system has also been investigated in crustaceans by another method. During his classical studies on the sinus-gland Hanström eliminated the X-organ as a potent source of pigment-activating hormones, because extracts of that portion of the eye-stalk in which it lay had only slight pigment-activating potency. Yet the sinus-gland, so rich in pigment activators, is mainly the swollen tips of fibres which originate in the X-organ, so it is surprising that extracts of the X-organ had so little effect. In fact, fresh extracts of the X-organ alone are without any effect, yet if such extracts are first boiled, or treated with alcohol, and are then injected, a very powerful effect is obtained (figure 20). It is possible that pigment-activating substances are present in the X-organ in a combined form, perhaps bound to some substance and thereby inactivated, and that boiling breaks the bond and frees the active molecule. Such a concept would be in accordance with the different staining reactions of droplets found in the cell-bodies of the X-organ, along the axon fibres, and in the swollen fibre tips of the sinus-gland. It is perhaps not premature to speculate whether the pigment-activating hormones may be stored in an inactive form in the cell-bodies of neurosecretory fibres. Later they may be converted into a form which can bring about pigment movements if it is artificially introduced into the blood stream, even though it does not normally pass into it. This latter substance may be present in the fibres and in their terminations. Finally, enzymatic action may fracture such a prohormone into active substances of low molecular weight, each having specific effects on particular pigments. This concept accords with our

## Plate I



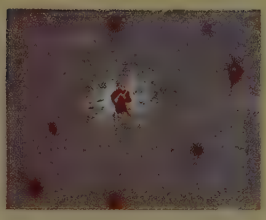


FIGURE 1 (*left*) – *A group of expanded chromatophores* (*large red, small red, and white*). (× 50)

FIGURE 2 (*above*) – *Some of the chromatophores shown in figure* 1, *shown after some concentration of the pigments.* (× 50)

FIGURE 3 (*right*) – *A dorsal view of the cephalothorax of* Leander serratus, *illustrating the three chromatophore types shown in figure* 1. (× 4)

FIGURE 4 – *The edge of one of the uropods, showing all pigments moderately dispersed* (*cf. figure* 12). (× 25)

FIGURE 5 – *A common European prawn,* Leander serratus, *that has recently been placed on a dark background. The dark pigments are moderately, though not maximally, expanded. (Natural size)*

FIGURE 6 – *Edge of a uropod. Pigments dispersed in the peripheral chromatophores, concentrated elsewhere.* (× 50)

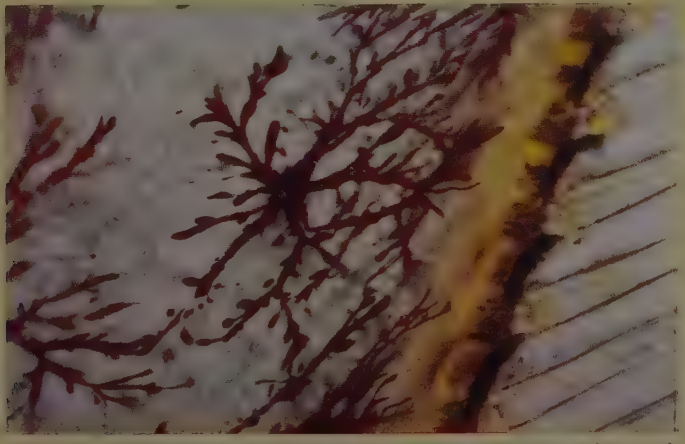


FIGURE 7 – *A uropod chromatophore in which concentration of the pigment has recently begun. The pigment has withdrawn from the finer chromorhizae, which are therefore no longer visible.* (× 200)

PLATE II

FIGURE 8 – *An eyeless individual which had been injected with sinus-gland extract (one gland in 0·05 ml sea-water).*

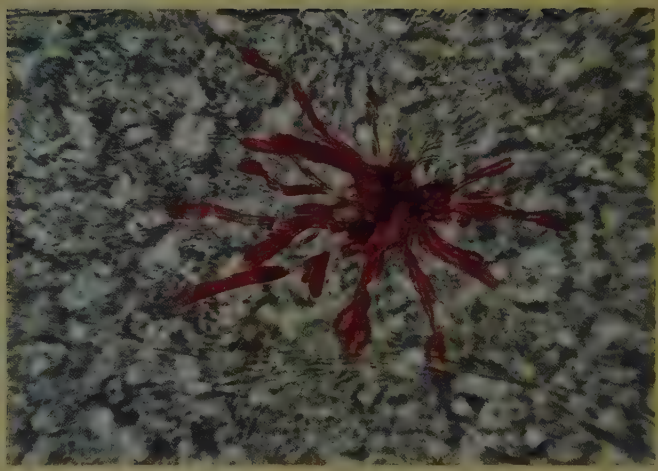


FIGURE 9 – *Uropod chromatophore of an animal injected with sinus-gland extract. The pigments are concentrated sharply and the red pigment has become transformed into a blue one which has left the chromatophore and caused a blueing of the tail.* (× 300)

FIGURE 10 – *Effects of post-commissure organ extracts.* (a) *Sea-water (control);* (b) *Squilla organ extract;* (c) *Leander organ extract. Both extracts concentrated white and large red chromatophores; Leander extract also dispersed those in tail.*

FIGURE 11 – *Comparison between the effects of sinus-gland and post-commissure organ extracts.* (a) *Control animal injected with 0·05 ml sea-water;* (b) *injected with 0·05 ml of sea-water extract of two sinus-glands;* (c) *injected with similar extract of two post-commissure organs;* (d) *injected with 0·05 ml sea-water. The eyeless animals had been deprived of their eyes four weeks before injection; the photograph was taken two hours after injection.*

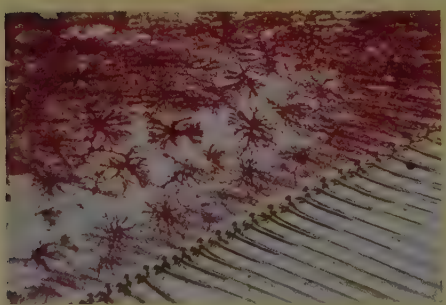


FIGURE 12 – *Portion of the tail of the animal shown at 10(c), showing maximal dispersal of the tail pigments. Compare with figures 4, 6, and 7.* (× 20)

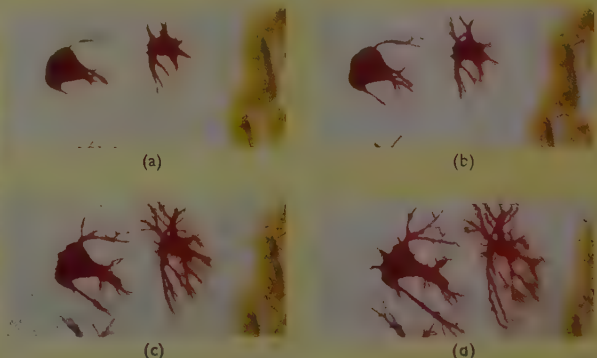



FIGURE 13 – *Successive stages in the expansion of two uropod chromatophores.* (× 100)

## PLATE III

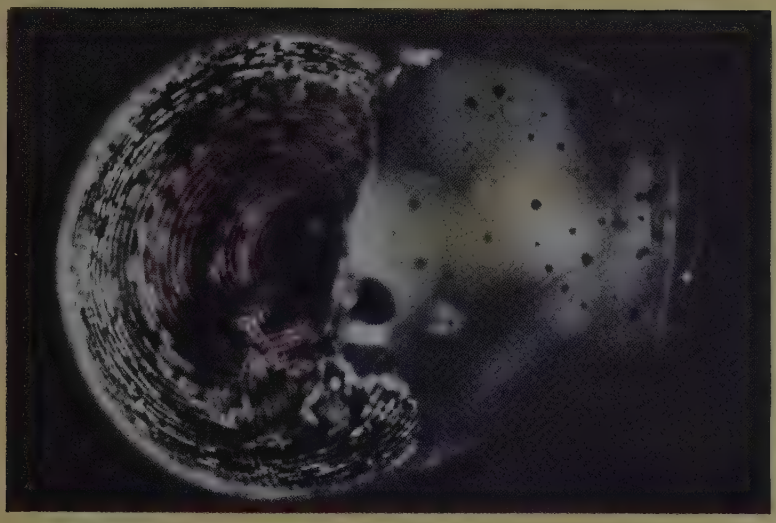


FIGURE 14 – *The left eye and eyestalk of* Leander serratus *viewed from above a few minutes after it had been detached from the animal. For identification of the visible structures see figure* 23. *There is some evidence that the disposition and form of the nervous and the neurosecretory structures of the eyestalk differ slightly in the Mediterranean and British forms of the species; this individual was taken at Naples.* (× 30)

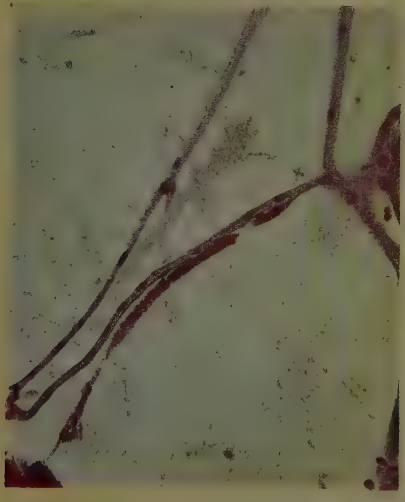


FIGURE 15 – *A transverse section through the post-commissure plate of* Penaeus braziliensis, *showing that it lies alongside, and is attached to, the wall of a blood-sinus, and that it contains structures which stain with azocarmine.* (× 150)

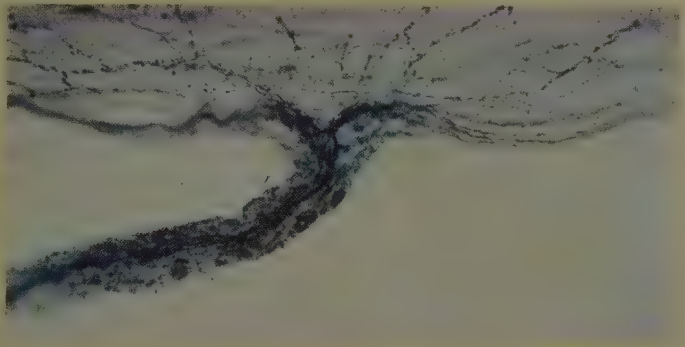


FIGURE 16 – *A methylene blue preparation of a portion of the commissure and the base of a post-commissure organ of* Leander serratus. *Fine neurosecretory fibres and droplets in the epineurium are visible.* (× 70)

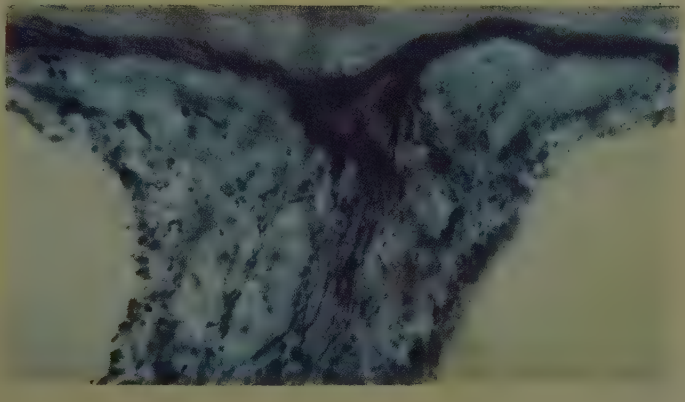


FIGURE 17 (*right*) – *A more highly magnified view of a portion of the area shown in figure* 16. *Peripheral droplets and a central bundle of neurosecretory fibres can be seen.* (× 350)

## PLATE IV

*Electrophoretic experiment.* 3 *milliamperes.* 16 *hours at* pH 7·49

| −5 | −4 | −3 | −2 | −1 | 0 | +1 | +2 | +3 | +4 | +5 |
|---|---|---|---|---|---|---|---|---|---|---|
| Small red chromatophore concentrator | No effect | No effect | No effect | Pigment concentrating substance | Pigment dispersing substance | No effect | Small red chromatophore concentrator | No effect | No effect | No effect |

FIGURE 18 – *Electrophoretic separation of pigment-activating substances from an extract containing ten post-commissure organs. Under the conditions of this experiment a substance which dispersed the body and tail chromatophores remained close to the point of application to the paper, slightly displaced towards the anode, but a pigment-concentrating substance which affected large red, small red, and white chromatophores, moved 2–3 cm in the direction of the cathode. Other, more mobile, substances, affecting only single pigments, were also found. Photograph taken* 30 *minutes after injection.*

FIGURE 19 – *Separation by dialysis: half an hour before this photograph was taken the left-hand animal received the fraction of a post-commissure extract that had passed through a Cellophane membrane. The right-hand animal received the fraction which did not pass through.*

FIGURE 20 – *Activation of X-organ extracts.* (a) *Animal injected with X-organ extract;* (b) *animal injected with a boiled extract of X-organ;* (c) *animal injected with untreated X-organ extract;* (d) *animal injected with alcohol-treated X-organ extract.*

FIGURE 21 – *The animal on the left had been injected half an hour before this photograph was taken with the fraction of a sinus-gland extract that had passed through a Cellophane membrane. The right-hand animal received the fraction which did not pass through.*

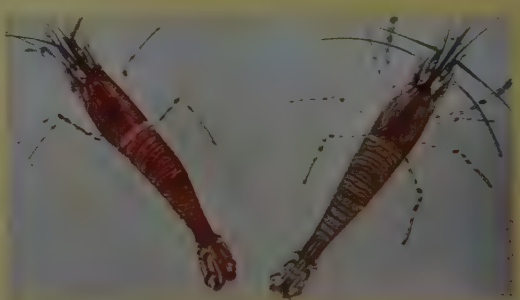


FIGURE 22 – *As figure* 21, *but using an extract of the* −1 *fraction* (*see figure* 18) *after electrophoresis of a sinus-gland extract. This substance did not pass through a Cellophane membrane.*

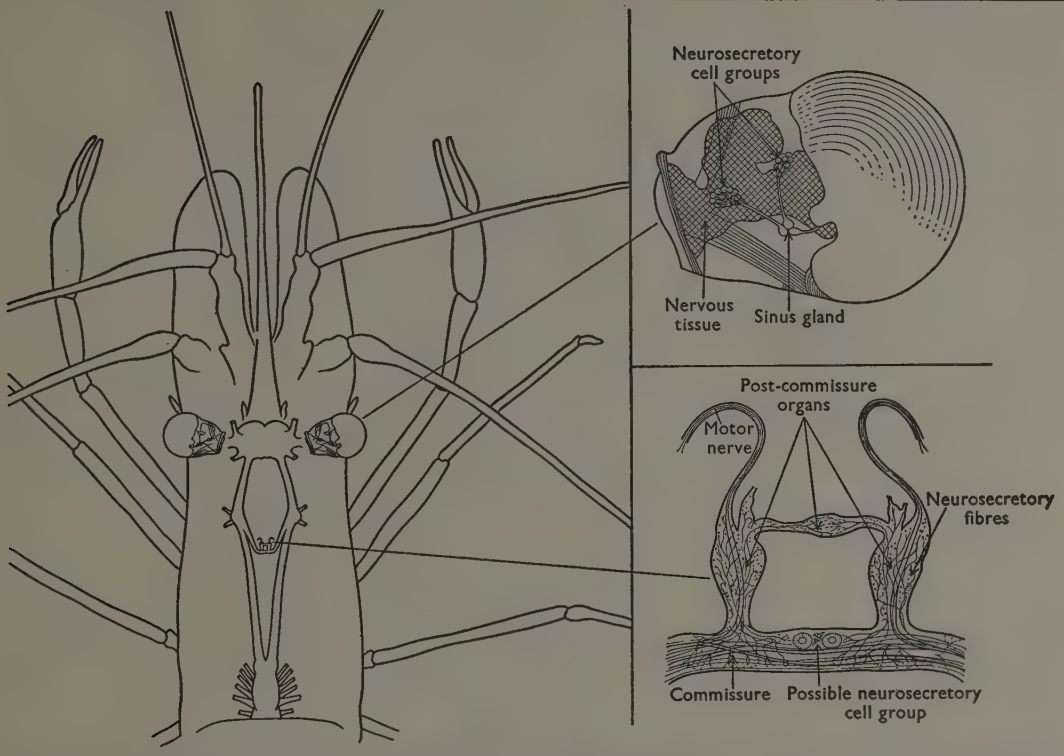



FIGURE 23 – *The position and the general appearance of the neurosecretory systems referred to in the text (compare with plate III). The arrangement of the neurosecretory fibres given is applicable only to* Leander serratus *and differs in other genera. The two neurosecretory cell groups in the eye-stalk have variously been described as X-organs in the literature; the proximal group is the one referred to as the X-organ in the present article.*

present state of knowledge, and it is to be hoped that electrophoresis and other studies may prove or disprove this working hypothesis.

## GENERAL CONCLUSIONS

The electrophoresis and dialysis experiments reported above show that antagonistic hormones may be present in neurosecretory systems. The post-commissure organs seem to contain both body-lightening and body-darkening hormones, which can be separated by physical means. In the sinus-gland of Leander it seems possible that there may be an anatomical separation of different pigment-activating hormones, for in this animal the sinus-gland is formed of three distinct parts, each the terminus of certain distinct nerve fibres, and it is possible to separate these portions and to make extracts of them separately. The portion which receives fibres from the X-organ seems to contain a substance that concentrates white chromatophore pigments, but the remainder of the sinus-gland seems to contain a white-pigment disperser. If this is so, it is likely that different neurosecretory fibres supplying the sinus-gland carry different substances. This raises an interesting problem: how is the controlled release of specific substances from neurohaemal organs effected? Bliss and Welsh have advanced the theory that neurosecretory cells may resemble efferent neurones in so far as they trigger the release of their own products, as an efferent neurone controls the release of the acetylcholine which it contains. However, this interesting theory has not yet received experimental support, though the apparent absence of innervation of the sinus-gland, except by neurosecretory fibres, makes the suggestion a reasonable one. If neurosecretory fibres also act as nerve fibres, in so far as they carry impulses to activate the release of their contained substances, then the resemblances between neurosecretory cells and typical neurones is a close one.

We are then faced with the difficulty of the precise definition of the word neurosecretion, which has been used by different authors in the

past with more than one meaning. On the one hand we have the histological definition used by Scharrer [18], whose precise and detailed work has done so much to gain acceptance of the general concept of neurosecretion; he has maintained that the term should be used only where evidence of active secretion by nerve cells can be visibly demonstrated by appropriate staining techniques, and in this sense it has been widely used recently. On the other hand we have the functional criterion used by Alexandrowicz, who has regarded fibres which appear to be efferent, yet do not apparently innervate any end-organ, as being, by inference, neurosecretory. It is probably still too early to attempt a final definition of neurosecretion, but it is used in the present article as a convenient term to describe the production and release of blood-borne hormonal substances by the central nervous system of crustaceans.

Such a control mechanism is a combination of nervous and hormonal action, and it is therefore pertinent to look for possible advantages of a neurosecretory process over control by purely nervous or purely hormonal means. A loss of speed in response is inevitable when chromatophores are activated by blood-borne substances instead of by direct innervation as they are in cephalopods, teleost fish, and reptiles, and it is logical to expect that some advantages of neurosecretory control may counterbalance the sacrifice of speed.

Simplicity of anatomical form seems to be one advantage of neurosecretion over direct nervous control. We have seen that very elaborate modifications of colour and pattern are effected in crustaceans by a system of relatively simple structure, though perhaps biochemically complex. Nervous control of such an elaborate colour pattern would have entailed a complex fibre system, but the relatively few fibres in the neurosecretory organs are evidently sufficient to select and release the appropriate hormones to activate the many pigments separately.

Nervous and hormonal control each have their special advantages and limitations. Nervous transmission is well suited to produce localized and immediate changes, such as muscle movements, which must be swift but which generally need not be long maintained. On the other hand, the processes of growth and development necessitate a widespread co-ordination of chemical change which need not be instantaneous but which must often be maintained for a considerable time, and this is effectively managed by the endocrine system. For the production of changes which must be fast and yet also be maintained, it is possible that a combination of nervous and hormonal control would be ideal. The accumulation of hormones in a neurosecretory complex permits slow and prolonged stimulation of the target organs without fatigue of the activating system, and yet the mechanism is sufficiently labile to allow sudden alterations in the intensity or direction of the hormonal release. In this respect neurosecretory control is particularly suitable for the sudden adaptive movements, superimposed on the slow rhythmical and prolonged changes, which characterize the colour-changes of crustaceans.

The photographs illustrating this article were taken with apparatus provided by the Nuffield Foundation, to which the author is greatly indebted.

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# Book reviews

ANIMAL CYTOLOGY

Animal Cytology and Evolution (*second edition*), *by M. J. D. White. Pp. xiv* + 454. *Cambridge University Press, London.* 1954. 45*s. net.*

The first edition of Dr White's book appeared in 1945 and was immediately recognized to be the best survey of the structure and behaviour of chromosomes to appear in the English language since Darlington's 'Recent Advances in Cytology' of 1937. He has now put us still further in his debt by revising his book to the extent of an almost complete rewriting. Although his major theme is the connection between chromosome number and structure and the processes of evolution, his book actually covers a somewhat wider field, and provides an introduction to the rapidly advancing studies on the biochemical nature of chromosomes and discussions on the mechanisms of mitotic and meiotic division.

A most valuable feature of the discussion is the breadth of the field from which evidence is drawn. In recent years our knowledge of the evolutionary changes in the chromosomes of Drosophila has achieved a remarkable depth and precision. The author gives a full account not only of the already classical researches of Dobzhansky and his co-workers, but also of the more recent, and perhaps less well known, studies of the Texas group of investigators under Patterson and Stone. But Drosophila is by no means allowed to remain in undisputed possession of the centre of the stage. The author's own extensive and important works on chromosome polymorphism in American grasshoppers adds a most welcome body of data from another group of organisms, and considerably broadens our ideas as to the kinds of changes which evolution may involve. He provides also a remarkably complete survey of studies on evolutionary cytology in all groups throughout the animal kingdom. His book will not only be of extreme value as a work of reference, but expounds in a very clear, and nearly always plausible, fashion the significance to be attached to the various observations, and is therefore a pleasure to read.

C. H. WADDINGTON

PLANT GROWTH

Growth and Differentiation in Plants, *edited by W. E. Loomis. Pp. viii* + 458. *Iowa State College Press, Ames.* 1953. 60*s. net.*

This is the second of the monographs, sponsored by the American Society of Plant Physiologists, which have the aim of presentation to a wider, though still technical, public than pure specialists. The sections therefore include mature as well as recent data, and reviews of theories, and even attempts to predict immediate developments. The field covered by the eighteen articles in this volume is extremely wide, ranging from the elongation of a cotton fibre to bio-electric fields, morphogenesis, and diseased growth. Some of the chapters, notably that on growth curves, are of a very elementary standard, others presuppose a good deal more background knowledge; as there are twenty-two authors such variations are only to be expected.

The study of plant growth is still in the phase of simple description, as is readily appreciated by reading the chapter on its 'elementary mathematics,' in which the approximately exponential multiplication of cells in young plants is for some reason called a logarithmic increase. For the most part it is possible to describe the known facts and relevant ideas in simple language, and this the authors have admirably succeeded in doing. By keeping jargon and esoteric terminology firmly within bounds they have achieved a most useful book, that should go far towards realising the aim set for it by its sponsors. It is to be feared that the high price will limit its usefulness in Britain.

W. O. JAMES

PHYSICAL CHEMISTRY

Physico-Chemical Methods (*fifth edition*), *by Joseph Reilly and William Norman Rae. Two volumes. Pp.* 760 *and* 800 *respectively. Methuen and Company Limited, London.* 1954. £7 10*s. net.*

This book was first published in 1926. In this fifth edition certain chapters of the earlier ones have been revised. A third, supplementary, volume appeared in 1945; this has not so far been revised.

Volume 1 deals with the measurements of length, mass, time, pressure, temperature, and various physical properties of materials, such as specific heat and viscosity. There are also sections describing low- and high-pressure apparatus, glassblowing, and low-temperature techniques. Volume 2 includes chapters on separation processes such as distillation and crystallization, spectrometry, electrical properties of solutions, dielectrics, thermionic vacuum tubes, and radioactivity. The book is very well printed and the figures and diagrams are, in most cases, extremely well drawn and where necessary show clearly details of construction.

In the preface Professor Reilly says: 'The subject matter has become so extensive . . . that it is very difficult for one person to undertake satisfactorily the actual revision.' This must certainly have been true, for the two volumes involve together about 1500 pages, and the weakness of the present edition is that in certain places the information is rather out-of-date. For example, there is a very small section on infra-red spectroscopy, a subject which has been greatly developed since the last edition was published. This subject should certainly be dealt with more fully and in a more up-to-date manner. It seems that in some places changes have been made by adding a further paragraph or two, and a few new references, to an old section. It would have been better if these could have been more suitably fitted into the existing text.

However, though certain parts of the book do not seem to have been revised sufficiently, there is much in both volumes that is extremely valuable, particularly as regards the description and explanation of the more established procedures and determinations. These presentations are most useful; and it is an undoubted advantage to have so much experimental information gathered together in one place.

J. W. LINNETT

AROMATIC COMPOUNDS

The Structures and Reactions of the Aromatic Compounds, *by G. M. Badger. Pp. xiv* + 456. *Cambridge University Press, London.* 1954. 63*s. net.*

The fact that such vast numbers of aromatic compounds are known perhaps accounts for the disproportionately large descriptive and preparative treatment accorded to them in most textbooks; the threads of theoretical interpretation are generally loose or tangled, and hidden by the masses of empirical data. There was thus certainly a need for such a book as this, in which the fundamental problems of

aromatic chemistry as a whole have been stripped of obscuring accretions, plainly stated, and thoroughly discussed. The first two chapters deal with the benzene problem and its theoretical solution, leading to the definition of an aromatic compound as a cyclic compound with a large resonance energy in which all the atoms of the ring take part in a single conjugated system. Dr Badger then considers typical properties of aromatic compounds, including addition reactions, substitution reactions, the Diels-Alder reaction, absorption and fluorescence spectra, photo-oxidation and photo-dimerization, and optical activity. A particularly useful chapter deals with the effects of substituents; here much information scattered throughout the literature is unified.

The book is intended for senior and post-graduate students, but many specialists will welcome it as providing a good conspectus of the whole field of aromatic theory. It is clearly written, well produced, and provided with indexes of subjects and names. One is only too acutely aware of present difficulties of printing and publishing, but as the literature cited goes, in practically all cases, only up to the middle of 1951, and as the preface is dated 1952, the delay in publication was regrettably long. E. J. HOLMYARD

THE GROWTH OF CHEMISTRY

From Classical to Modern Chemistry, *by A. J. Berry. Pp. xii* + 251. *University Press, Cambridge.* 1954. 25*s. net.*

This book captures the reader's interest at the start and holds it throughout. The author begins with an historical discussion of the place of certain theories in chemistry, and makes the valid point that explanations of chemical reactivity in terms of mechanics are never likely to have more than a limited degree of success. Mechanical conceptions, such as those of Baeyer's strain theory, have admittedly been very useful, but they fail in the end to explain the specific properties of individual substances. Even the classical theory of atoms and molecules, essential to the development of nineteenth-century chemistry, ultimately proved inadequate, and Mr Berry reminds us that most physics of the same period was based on the idea of matter as a continuum.

Succeeding chapters deal with vicissitudes of the theory of heat; aspects of classical electricity and electrolysis; physical optics and chemistry; molecular magnitudes; analytical chemistry; chemical formulae; problems of valency, radicals, and constitution; and kinetic chemistry. By thus treating of topics rather than of periods Mr Berry has employed a useful historical perspective, focusing attention upon the trees rather than upon the wood and improving our knowledge of both.

The book emphasizes the influence that physics has exerted upon chemistry, and both physicists and chemists will find in it much to interest them. Like other books from the same press, it is very well produced, and there are full indexes. E. J. HOLMYARD

MORPHINE ALKALOIDS

The Chemistry of the Morphine Alkaloids, *by K. W. Bentley, with a foreword by Sir Robert Robinson. Pp.* 433. *Oxford University Press, London.* 1954. 50*s. net.*

It is characteristic of the great extent of research on alkaloids that a book of more than four hundred pages is necessary for a comprehensive description of the results of the chemical investigation of the morphine alkaloids alone. With great experience, the author has included in this monograph a very great number of scientific investigations which have been carried out in recent decades with the aim of elucidating the constitution of morphine and its relatives. These investigations were finally crowned, and in a certain sense also carried to a conclusion, by the synthesis of these compounds.

Subdivision into twenty-eight chapters facilitates survey of the wealth of the material. The history and the beginnings of morphine research; the numerous degradation and rearrangement reactions of the alkaloids; and their biosynthesis and total synthesis *in vitro*, are described in detail. Everybody who wishes to get special information on this group will easily find his way about in this book and will be assisted by many references to original papers.

Bentley's book on the chemistry of the morphine alkaloids seems indispensable for anybody who is interested in this chapter of chemistry. It is a document testifying to the purposeful investigation which many scientists have devoted to these natural substances in recent decades. Sir Robert Robinson, one of the pioneers of morphine-alkaloid research, has written a foreword to the book. P. KARRER

CHEMICAL CALCULATIONS

Physicochemical Calculations, *by E. A. Guggenheim and J. E. Prue. Pp. xii* + 491. *North-Holland Publishing Company, Amsterdam.* 1955. 53*s. net.*

It has long been recognized by teachers of physical chemistry in universities that there is a gap between the experimental work described in original papers and the experiments that can be conducted in a teaching laboratory. Undergraduates should have the opportunity of critically handling data derived from experiments of types that they cannot be expected to observe themselves. They ought to read some original papers, but they cannot cover the whole field in this way. Professor J. H. Wolfenden's *Numerical Problems in Physical Chemistry* (Oxford, 1938) was directed towards filling the gap, by providing numerical data from original papers and leaving the student to compute from them, with the aid of some hints, the relevant quantities. Professor Guggenheim and Dr Prue have produced another solution to the problem; the difference is that the calculation is done in the text. Each of the 171 problems is set out clearly, with references to the original work; the principle of the calculation is briefly indicated (references to standard textbooks might have been included); the calculation is then performed and the result critically commented upon. The selection of problems is broad and representative. The book will be extremely useful in university teaching, but it is a pity that the price is so high. E. F. CALDIN

VEGETABLE FATS

Vegetable Fats and Oils, *by E. W. Eckey. Pp. ix* + 836. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 132*s. net.*

This volume is the successor to G. S. Jamieson's well-known 'Vegetable Fats and Oils,' first published in 1938. It is planned on different lines, but in some respects the altered arrangement seems to present no improvement. It is a comprehensive and systematic survey of practically all fats of the vegetable kingdom which have so far been examined; of their general characteristics and, where available, their detailed composition; of their specific properties and, where these are of technical interest, their current industrial utilization.

The first seven chapters are general discussions of the chemical and physical nature of vegetable fats, their nutritional aspects, the genesis of fats in

plants, and a survey of analytical methods. The treatment varies somewhat in excellence and is liable at times to be rather diffuse. The general account of the composition of plant fats is very well done indeed, but their biochemical aspects and their genesis deserve fuller discussion than they have received. The treatment of the manner in which sugar may be converted into fat in the seeds of plants, in particular, relates mostly to old work and takes no account of several recent contributions.

The greater part of the book, as in its predecessor, is rightly devoted to descriptions of individual plant fats. Jamieson arranged these alphabetically, first dividing the vegetable fats into the then conventional rough groupings of non-drying, semi-drying, and drying oils. The latter divisions are admittedly not very serviceable, and it is more satisfactory to group fats according to their chief component acids. It is then seen that the seed fats of a particular plant family, or of several plant families, may frequently have common features. Eckey, however, has gone further and has classified the vegetable fats strictly according to the botanical orders to which the plants belong. In the present state of knowledge this seems to confuse rather than to simplify the apparent relations of plant fat composition with botanical sources. For example, the seed fats of the families Rosaceae, Euphorbiaceae, and Cucurbitaceae have certain broad features which make their consideration together not unreasonable; yet these families fall in three different orders, Rosales, Geraniales, and Campanulales respectively. Conversely, in the Geraniales are included not only Euphorbiaceae (species of which may yield seed fats rich in linolenic, elaeostearic, ricinoleic, or other acids) but Linaceae (linseed oil), Rutaceae (citrus oils, rich in palmitic as well as linoleic acid), and Meliaceae (seed fats often rich in stearic as well as other acids). The readers for whom this book is primarily intended will be more interested in the composition of the fats than their ultimate botanical origin, and, despite the index, they might have preferred a treatment based more simply on the constitutive similarities of specific fats.

There is much in this volume which merits commendation: it is designedly written with the needs of American readers primarily in mind, but it will be of interest to wider circles. It is well printed, clearly arranged, and adequately indexed. T. P. HILDITCH

INFRA-RED SPECTROSCOPY

The Infra-red Spectra of Complex Molecules, *by L. J. Bellamy. Pp. xv + 321. Methuen and Company Limited, London.* 1954. 35*s. net.*

In spite of the remarkable and rapid advance of infra-red spectroscopy into physical and organic chemistry few books are yet available for the guidance of those research workers who now have to use the technique with little or no previous training in it or knowledge of the relevant theory. Any text of this kind will therefore command a wide interest. This book deals very thoroughly with one particular aspect of the study of complex molecules, namely structural diagnosis by means of the infra-red absorption spectrum. The method is based upon the fact that certain atomic groupings give rise to vibration frequencies of about the same magnitude in different molecules, regardless of the rest of the molecular structure. Such groups may therefore be identified by absorption bands which appear at characteristic positions. Since absorption spectra can now be measured easily using very small quantities of material, there is a potentially powerful method for the study of natural and synthetic products, the success of which has already been established in some spectacular cases.

The author has presented a comprehensive survey and summary of all the significant correlations so far discovered, detailed attention being given to different types of carbon-hydrogen bond in hydrocarbons, to the variety of carbonyl groups and of nitrogen-hydrogen bonds, and to ring systems of various sorts. Anyone concerned directly with this field will find this review, with its exhaustive bibliography, a most valuable work of reference. The author has also tried to indicate the circumstances in which the correlation rules are unreliable. This is a very important point, since there may at present be a tendency to apply this diagnostic weapon without due caution. Many factors, some of which are not yet fully understood, may cause displacement of the key bands, and the experienced worker will bear this in mind when analysing his results. In fact, some may regard with a degree of uncertainty a few of the interpretations used by the author in his illustrative diagrams. One of the difficulties arises because the intrinsic intensity of a given group vibrational band may alter considerably from one molecule to another, and there has hitherto been little constructive study of this matter.

This book, although rather expensive for its size, is a valuable collection of the relevant information, and, although too exhaustive for the student reader, will be very useful for the specialist or industrial organic chemist.

H. W. THOMPSON

ISOTOPE GEOLOGY

Isotope Geology, *by K. Rankama. Pp. xvi + 535. Pergamon Press Limited, London.* 1954. 75*s. net.*

Since the war the applications of nuclear physics to geology have extended and multiplied so rapidly that the subject has become a trackless jungle where the student's only guides are the often contradictory original papers. Professor Rankama has taken this great mass of information and reduced it to order. The first 150 pages give an elementary review of the relevant properties of stable and radioactive nuclei. This is followed by about 300 pages in which each element is considered in turn. Finally there is a bibliography of about 1300 references, including some as recent as 1954.

The subjects treated include the determinations of the ages of rocks, using, among other methods, those depending on uranium, lead, strontium, rubidium, potassium, argon, and carbon; the age of the earth's crust and of the elements, palaeo-temperatures from $O^{18}:O^{16}$ ratios; and the biological fractionation of sulphur, and its bearings on the date of appearance of bacteria. The approach is that of a geochemist rather than a geologist, and hardly touches the problem of integrating this new body of knowledge with the rest of geology. Probably the author was wise in this—what was needed was a critical compilation and review, and this he has provided.

The printing, production, and paper of the book are of the usual high standard of the Pergamon Press. The reader should not be deterred by 'exactization' and 'synoptical' in the first paragraph of the preface; the English of the rest of the book is excellent.

E. C. BULLARD

GEOCHEMISTRY

Geochemistry, *by the late V. M. Goldschmidt, edited by Alex Muir. Pp.* 730. *Oxford University Press, London.* 1954. 63*s. net.*

The author's modest preface to this book, which begins: 'It is, of course,

very difficult for any single author to cover the whole field of geochemistry', tends to conceal a much more significant fact—that few people have made such a major contribution to any subject, even in its infancy, as Goldschmidt made to the field which will always be associated with his name. The book is in the nature of an unfinished symphony, for Goldschmidt was unable to finish it before his death. The editor must be congratulated on a remarkable achievement in piecing together the intended text of the book, so far as it had been completed, previous publications by the author necessary to round off certain sections, and other material, sometimes written up from notes and sometimes contributed by those in touch with Goldschmidt's work. One might have expected such a compilation to lack coherence, yet not only is the book extremely coherent, but it is readable and conveys the same sense of fascination as came from listening to, or conversing with, the author himself. For Goldschmidt could call upon his encyclopaedic knowledge to talk to mineralogist, chemist, geologist, crystallographer, or metallurgist on equal terms. The whole progress of modern chemistry has been profoundly affected by the work recorded here and by the theory and philosophy which Goldschmidt built upon it.

The detailed geochemistry of the various elements is largely as he wrote it; the more theoretical part is somewhat more synthetic. It is best that it should be this way, for the theories he propounded may naturally be modified in the light of later experiments and discoveries. The book, however, will stand as a monumental base for the subject, presenting, as he would have liked to see it, both the author's own contribution and the contemporary developments which they inspired.

F. M. BREWER

COAL

Coal, *by Wilfrid Francis. Pp. viii + 567. Edward Arnold (Publishers) Limited, London.* 1954. 84*s. net.*

In 1918 Marie Stopes and R. V. Wheeler published a classic monograph on the constitution of coal. In less than 50 pages they reviewed critically the meagre existing knowledge of the subject and indicated plainly the great field for study. In the thirty-six years that have elapsed since then nothing comparable in scope to this new book has been published. It is the direct heir of the famous monograph, and it is fitting that one of Wheeler's men should have undertaken for his own generation the great task of compiling a comprehensive and up-to-date survey of work bearing on the origin and constitution of coal. In doing this Dr Francis has achieved a large measure of success, and his work should be received with unreserved gratitude. In a short notice of this kind it would perhaps be fairest to leave it at that and to commend to all serious students of coal science an invaluable book of reference.

And yet, to the informed reader, there are steadily recurring questions to which the book provides no answers. Where have we got to in our attempts to elucidate the complexities of coal constitution ? Which of the many lines of attack have proved the most fruitful ? Where should new research be concentrated ? These are the problems that face the research worker today, and a critical judgment on them, though it would undoubtedly have introduced a controversial element, would have added greatly to the value of the book. This could profitably have been attempted in a concluding chapter. Apart from this lack of a critical analysis of the vast canvas displayed, the only other major criticism of the book must be of its inadequate treatment of physical researches on coal, which in recent years have so greatly added to our knowledge of coal structure. The short chapter dealing with this does much less than justice to the versatility, ingenuity, scope, and potentiality of the physicist's contribution. The book would have been strengthened by a collaborator here.

It would be churlish, however, to close on a note of criticism. Clearly this is an outstanding book and a remarkable achievement on the part of one man. It is beautifully printed and superbly illustrated.

A. M. WANDLESS

MEMOIRS

Obituary Notices of Fellows of The Royal Society, *Volume 9. Pp. 264. The Royal Society, London.* 1954. 30*s. net.*

In a recent review in these columns Sir Henry Dale referred to the potential value to future scientific historians of intimate reminiscences of men who seem likely to retain their important stature in the longer perspective of future appraisement. Outstanding among such reminiscences are the official obituary notices of Fellows of the Royal Society, now published annually by the Society as a separate volume. Prepared with most meticulous care and from every available source, these notices will certainly be invaluable in the future, when documents are lost and living memory no longer there, but they also have a present value additional to their immediate purpose of paying tribute to great scientists whose work is done. Within them will be found much that is already of historical interest, for in the very nature of things much of a man's most original work is done comparatively early in life. Many of the notices contain concise and clear accounts of discoveries and theories which were revolutionary in their day but have already gained general acceptance. To take at random an example from the present volume, Sir Henry Tizard's obituary of N. V. Sidgwick contains, apart from a wealth of personal detail, a most interesting account of the development of the electronic theory of valency.

The importance as works of reference of these excellently produced volumes deserves to be much more widely appreciated than it is.

TREVOR I. WILLIAMS

HISTORY OF SCIENCE

Science in History, *by J. D. Bernal. Pp. xxiv + 967. C. A. Watts and Company Limited, London.* 1954. 42*s. net.*

This book is an attempt to describe and interpret the relations between the development of science and that of other aspects of human history. Professor Bernal's enterprise is a great one—so great that one may ask whether it can be profitably undertaken. To do it well the author should know all science and all history—and not merely the events of history but the changing attitude of man towards his world. To say that Professor Bernal does not know all this is no dispraise, but the limitations of human faculty have made it necessary that he should rely, not on the ultimate facts of history and of science, but on the generalizations and conclusions of other men. These are often controversial, but in a book of this scope the argument and counter-argument are necessarily omitted and we have to rely very largely upon the author's judgment of controversies and his selection of generalizations on which to base his arguments. Professor Bernal cannot,

however, be called an unbiased investigator: he starts with strong political views of the extreme left wing and also with the conviction that the content of religion is nonsense. He can, therefore, be accepted as a guide only by those who share such views, and so his book is not one to be used as an authority by those new to the subject. Nevertheless, the whole of the text is of great interest. Professor Bernal brings a keen mind to bear on the relations of science and history, and no one can read the book without finding a hundred statements controversial enough to provoke new trains of thought. It is, I believe, the first book of its kind, and the man who breaks new ground earns our gratitude, even though he bring in weeds with his harvest. F. SHERWOOD TAYLOR

INDUSTRIAL HISTORY

A Merseyside Town in the Industrial Revolution: St Helens 1750–1900, *by T. C. Barker and J. R. Harris. Pp. xviii + 508. University Press of Liverpool, Liverpool.* 1954. 30*s. net.*

This well-documented story of the growth of a hamlet to an important industrial town of some 85 000 inhabitants is primarily a social and economic study. It contains, however, a great deal of information of value to the serious student of the history of the scientific industries, especially the chemical industry. Of particular interest is the way in which the siting and development of industry can be affected, perhaps decisively, by what may seem to be in themselves trifling factors. Thus the neglect of the alkali manufacturers, in 1845, to take an opportunity of having the ton legally as well as practically defined—for the purpose of carrying their raw materials on the Sankey Canal—as 3360 pounds (the long ton) instead of 2240 pounds (the imperial ton), was in large measure responsible for the ultimate eclipse of St Helens by Widnes as a chemical manufacturing centre.

The technical development of the glass industry, for which St Helens is world famous, is described in some detail, as is that of the once flourishing copper-smelting works. Though brief, the account of the long struggle between the ammonia-soda and the Leblanc process, culminating in the formation of the United Alkali Company Limited, in 1890, contains a great deal of useful detail not otherwise easily obtainable.

TREVOR I. WILLIAMS

HISTORY OF MATHEMATICS

The Mathematical Practitioners of Tudor and Stuart England, *by E. G. R. Taylor, with a foreword by Sir Harold Spencer Jones. Pp. xi + 443. Cambridge University Press, London, for the Institute of Navigation.* 1954. 55*s. net.*

The practitioners were the instrument makers, surveyors, teachers of mathematical arts and of navigation, and others who were active in science, but not great scientists. For the period 1485–1715 Professor Taylor has compiled biographical notes on 582 persons and described 628 of the books they wrote. She has thereby rendered a signal service to bibliographers and historians of science: the greater part of the material has been newly collected from original sources, but even the small amount previously available was scattered through some dozens of works of reference. This book initiates a revolution in the historiography of sixteenth- and seventeenth-century science; the stage has now been peopled with the numerous minor characters without whom the principals could not have worked and cannot now be properly understood.

In addition to the notes, the author has provided a continuous narrative describing the evolution and progress of the practitioners and showing the importance of their contributions. The general reader will find it illuminating as a new perspective, the specialist will benefit from the large amount of historical research which is now presented for the first time. D. J. PRICE

EARLY MEDICAL BOOKS

A Catalogue of Incunabula in the Wellcome Historical Medical Library, *by F. N. L. Poynter. Pp. xv + 160. Oxford University Press, London, for the Wellcome Historical Medical Museum.* 1954. 50*s. net.*

Incunabula are books printed when printing was in its swaddling-clothes, that is to say from the time of its invention, about 1450, up to the end of the fifteenth century. A surprisingly large number of books were in fact printed during this period, and the present catalogue lists no fewer than 610 items—though some of the items are merely different editions of the same work. The late Sir Henry Wellcome had the 'ambition to obtain wherever possible the first, or at least a very early printed, edition of every medical work of any consequence'; his measure of success may be judged by the fact that the collection here described contains 117 items not found at the British Museum. Not all the books mentioned are wholly devoted to medicine, for at that time the lines of demarcation between various branches of learning were not sharply defined. Thus the Bible and the 'Nuremberg Chronicle' find place with Avicenna's 'Canon of Medicine' and Gilinus' *De morbo gallico*, and Ovid's *De arte amandi* with Galen's *Therapeutica*.

In his catalogue, Mr. Poynter gives references to the standard bibliographies of incunabula, but adds such details about the Wellcome copies as provenance, signatures, manuscript notes, early bindings, former ownership, and immediate provenance. He also provides indexes of names, subjects, marks of ownership, printers, countries and towns, and chronology. There are twelve plates. In helping to fulfil Sir Henry's object of 'making available to students of the history of medicine the original texts which are the basis of their study', this catalogue should find a place in every medical and scientific reference library. E. J. HOLMYARD

CARTESIAN GEOMETRY

The Geometry of René Descartes (translated by D. E. Smith and M. L. Smith). *Pp. 243. Dover Publications Inc., New York.* 1954. $1.50 *paper;* $2.95 *cloth.*

Cartesian geometry and Cartesian co-ordinates are terms with which the schoolboy student of mathematics is early made familiar, and serve to remind us of the prime importance of the *Géométrie* of René Descartes, in which the analytical method was first systematically developed. The treatise first came out in 1637, as, in a way, a supplement to the *Discours de la Méthode*, not only bound up with, but paged as part of, that book; it did not appear as a separate work until 1664. The early French editions are very rare, and Latin, in which less rare editions appeared, is not today a language familiar to the average student of the history of science.

In 1925 the Open Court Publishing Company, with the student's need in view, brought out a facsimile of the original edition of 1637, with an English translation, by David Eugene Smith, the well-known historian of mathematics, and Marcia L. Latham, printed on pages opposite the text. This is of service to those to whom the French, in

an orthography somewhat different from that now in use, might offer difficulty. The edition now issued by Dover Publications appears to be a photographic copy, in a somewhat reduced size, of the Open Court publication, but there is no reference to this, that the reviewer can find, except that the Open Court Company is named in the *Preface*, which, as it appears in photographic reproduction of the original preface, could scarcely be avoided. This lack of acknowledgment of a previous publication appears to be a policy of Dover Publications: their recent reissue of Newton's *Opticks*, with a foreword by Einstein and an introduction by E. T. Whittaker, was a reprint of the edition brought out in 1931 by G. Bell and Son, for which the preliminary articles were originally written; but there was no reference to this fact. No doubt the legal formalities have been observed, but the practice of reprinting without acknowledgment is not a very gracious one.

The copy before us is paper covered and held together by stabbed wires, which no doubt is one factor making for the cheapness that has been achieved. Of the 'higher priced cloth edition' at $2.95, to which reference is made on the cover, no copy has been furnished.

E. N. DA C. ANDRADE

PHARMACEUTICAL CODEX

The British Pharmaceutical Codex 1954. *Pp. xxxii* + 1340. *The Pharmaceutical Press, London.* 1954. 63*s. net.*

The appearance of a new edition of the British Pharmaceutical Codex only five years after the preceding one is an indication of the present high rate of change in medicinal treatment, for the previous intervals were all of more than ten years. The functions of the Codex remain unchanged. While primarily a book of reference for those prescribing and those dispensing medicine, it is secondarily a book of standards for substances not included in the British Pharmacopoeia. Like the Pharmacopoeia, the Codex is prepared by a number of committees, each concerned with one aspect of pharmaceutical work. The result therefore represents a mass of very valuable information, because it is selected with care by those familiar with both the theory and the practice of their subject.

The book is four hundred pages shorter than the 1934 Codex, and it is to be noted that 'the pressure on space exerted by new drugs of undoubted value is such that tradition or sentiment cannot be counted an adequate reason for inclusion.' This must have been a painful decision for many of those who helped in the compilation. The monographs with their structural formulae are admirably written and beautifully printed. The Pharmaceutical Society is to be warmly congratulated on this fine work.

J. H. BURN

PHOTOGRAPHIC THEORY

The Theory of the Photographic Process (*revised edition*), *by C. E. K. Mees. Pp.* 1133. *The Macmillan Company, New York.* 1954. $21.50 *net.*

Under the general editorship of the vice-president in charge of research of the Eastman Kodak Company, an outstanding group from the Kodak laboratories at Rochester and at Harrow has produced a unique account of the photographic process in this volume of over a thousand pages. The first edition, published in 1942, quickly established itself as a critical and authoritative guide to the subject. Advances made since then, many of them resulting from researches in the Kodak laboratories, have necessitated extensive revision of the text and the rewriting of many of the chapters. New chapters have been added on the photographic effects of charged particles and of X-rays. Part III, on optical sensitizing, provides a particularly valuable account of this field and incorporates much new material.

The photographic process will provide fruitful subjects for research for many years to come. Chemists and physicists who are led to photographic research by the stimulating references to unsolved problems will join all who are concerned with the theory of the photographic process in acknowledging indebtedness to Dr Mees for the policy which has allowed members of his staff to engage in such a large proportion of fundamental research, to publish the scientific results of their investigations, and to present their considered views in this comprehensive volume.

J. W. MITCHELL

# Some books received

(*Note.* Mention of a book on these pages does not preclude subsequent review.)

ASTRONOMY

Meteor Astronomy, *by A. C. B. Lovell. Pp. xiv* + 463. *Oxford University Press, London.* 1954. 60*s. net.*

BIOLOGY

Aspects of Deep Sea Biology, *by N. B. Marshall. Pp.* 380. *Hutchinson's Scientific and Technical Publications, London.* 1954. 35*s. net.*

Biology of Deserts, *edited by J. L. Cloudsley-Thompson. Pp.* 224. *Institute of Biology, London.* 1954. 14*s. net.*

Einführung in die Biologische Registriertechnik, *by H. Klensch. Pp. x* + 222. *Georg Thieme Verlag, Stuttgart.* 1954. *D.M.* 33.

The Genetics of *Paramecium Aurelia*, *by G. H. Beale. Pp.* 179. *Cambridge University Press, London.* 1954. 12*s.* 6*d. net.*

The Natural Regulation of Animal Numbers, *by D. Lack. Pp.* 343. *Oxford University Press, London.* 1954. 35*s. net.*

Probleme und Beispiele Biologischer Regelung, *by R. Wagner. Pp.* 219. *Georg Thieme Verlag, Stuttgart.* 1954. *D.M.* 29.70.

CHEMISTRY

The Chemistry of Lipids of Biochemical Significance, *by J. A. Lovern. Pp. xiii* + 132. *Methuen and Company Limited, London.* 1955. 8*s.* 6*d. net.*

Atomic and Free Radical Reactions, *Volumes* 1 *and* 2 (*second edition*), *by E. W. R. Steacie. Pp. x* + 901. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. £11 4*s. net.*

The Elements of Chromatography, *by T. I. Williams. Pp.* 90. *Blackie and Son Limited, Glasgow.* 1954. 9*s.* 6*d. net.*

Émulsions, Mousses, Détersion, *by P. Cor. Pp. xvi* + 129. *Dunod, Paris.* 1955. *Fcs* 980 *net.*

Geochemie seltener und nur in Spuren vorhandener chemischer Elemente im

Boden, *by A. P. Winogradow. Pp.* 249. *Akademie-Verlag, Berlin.* 1954. *D.M.* 23.

Ephraim's Inorganic Chemistry (*sixth edition*), *by P. C. L. Thorne and E. R. Roberts. Pp. xii* + 956. *Oliver and Boyd Limited, Edinburgh.* 1954. 35*s. net.*

Isotopic Gas Analysis for Biochemists, *by R. F. Glascock. Pp. viii* + 247. *Academic Press Inc., New York; Academic Books Limited, London.* 1954. $5.80.

Manuel Technique d'Analyse Microbiologique du Sol, *by J. Pochon. Pp. viii* + 123. *Masson et Cie, Paris.* 1954. *Fcs* 750 *net.*

Mass Spectrometry, *by A. J. B. Robertson. Pp.* 135. *John Wiley and Sons Inc., New York; Methuen and Company Limited, London.* 1954. 8*s.* 6*d. net.*

Solvent Properties of Amphiphilic Compounds, *by P. A. Winsor. Pp. ix* + 207. *Butterworths Scientific Publications, London.* 1954. 40*s. net.*

Chemistry and Biology of Pteridines (a Ciba Foundation Symposium), *edited by G. E. W. Wolstenholme and Margaret P. Cameron. Pp. xiv* + 425. *J. and A. Churchill Limited, London.* 1954. 42*s. net.*

GENERAL

La Cybernétique; "Du Cerveau Humain aux Cervaux Artificiels," *by P. Cossa. Pp.* 98. *Masson et Cie, Paris.* 1955. *Fcs* 525 *net.*

English for the Scientist (*fourth edition*), *by C. Duval. Pp.* 96. *Centre National de la Recherche Scientifique, Paris.* 1954. *Fcs* 450 *net.*

First Voyage, *by John Guyther. Pp.* 208. *Andrew Melrose Limited, London.* 1954. 16*s. net.*

The Kinetic Basis of Molecular Biology, *by F. H. Johnson, H. Eyring, and M. J. Polissar. Pp. vii* + 874. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 120*s. net.*

Psychology as the Study of Behaviour (an Inaugural Lecture), *by O. L. Zangwill. Pp.* 36. *Cambridge University Press, London.* 1954. 2*s.* 6*d. net.*

Radioisotope Conference 1954. Volume II: Physical Sciences and Industrial Applications, *edited by J. E. Johnston, R. A. Faires, and R. J. Millett. Pp. ix* + 223. *Butterworths Scientific Publications, London.* 1954. 45*s. net.*

Scientific Books, Libraries and Collectors, *by J. L. Thornton and R. I. J. Tully. Pp. x* + 288. *The Library Association, London.* 1954. 24*s. net.*

The Technical Report: Its Preparation and Use in Industry and Government, *edited by B. H. Weil. Pp. xii* + 485. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 96*s. net.*

United Kingdom Postgraduate Awards, 1954–5. *Pp.* 117. *The Association of Universities of the British Commonwealth, London.* 1954. *N.p.*

GEOLOGY

General Principles of Geology, *by J. F. Kirkaldy. Pp.* 327. *Hutchinson's Scientific and Technical Publications, London.* 1954. 25*s. net.*

Geology of Petroleum, *by A. I. Levorsen. Pp. x* + 703. *W. H. Freeman and Company, California; Bailey Bros. and Swinfen Limited, London.* 1954. 68*s. net.*

MATHEMATICS

A Budget of Paradoxes, *by Augustus de Morgan* (with a new introduction by E. Nagel). *Pp.* 387. *Dover Publications Inc., New York.* 1954. $4.95 *cloth net.*

The Psychology of Invention in the Mathematical Field, *by J. Hadamard. Pp. xiii* + 145. *Dover Publications Inc., New York.* 1954. $2.50 *cloth;* $1.25 *paper net.*

MEDICINE

Fluoridation as a Public Health Measure, *edited by J. H. Shaw. Pp. v* + 232. *A.A.A.S., Washington, D.C.; Bailey Bros. and Swinfen Limited, London.* 1954. 40*s. net.*

The National Formulary 1955. *Pp.* 210. *The Pharmaceutical Press, London.* 1955. 5*s. ordinary;* 8*s. interleaved net.*

Serological Approaches to Studies of Protein Structure and Metabolism, *edited by W. H. Cole. Pp. xi* + 97. *Rutgers University Press, New Jersey.* 1954. $2 *net.*

Trattato di Istologia, *Volumes* 1 *and* 2, *by Giuseppe Levi. Pp. xvi* + 1171. *Unione Tipografico-Editrice Torinese, Turin.* 1954. *L.* 12 000.

Dust is Dangerous, *by C. N. Davies. Pp. xvii* + 116. *Faber and Faber Limited, London.* 1954. 21*s. net.*

Mensche und Mikrobe; Abenteuer im Unsichtbaren, *by F. Bolle. Pp.* 396. *Safari-Verlag, Berlin.* 1954. *D.M.* 16.80.

Strahlendosis und Strahlenwirkung, *by B. Rajewsky. Pp.* 112. *Georg Thieme Verlag, Stuttgart.* 1954. *D.M.* 11.

PHILOSOPHY

The Sources of Eddington's Philosophy, *by H. Dingle. Pp.* 64. *Cambridge University Press, London.* 1954. 3*s.* 6*d. net.*

Vom Sein und Sollen des Menschen, *by H. Muckermann. Pp.* 344. *Westliche Berliner Verlagsgesellschaft Heeneman KG, Berlin-Wilmersdorf.* 1954. *D.M.* 22.50.

Die Welt sieht anders aus unser Weg ins Atomzeitalter, *by W. D. Müller. Pp.* 287. *R. Oldenbourg, Munich.* 1954. *D.M.* 15.80.

PHYSICS

Advanced Level Examples in Physics, *by R. V. Johns and W. F. Ware. Pp. viii* + 346. *Macmillan and Company Limited, London.* 1954. 16*s. net.*

Analysis of Deformation, *Volume* 2, *by K. Swainger. Pp. xxxvi* + 365. *Chapman and Hall Limited, London.* 1954. 70*s. net.*

Dynamical Theory of Crystal Lattices, *by Max Born and Kun Huang. Pp. viii* + 420. *Oxford University Press, London.* 1954. 50*s. net.*

The Physics of Particle Size Analysis (Conference arranged by the Institute of Physics, from 6th to 9th April, 1954), *British Journal of Applied Physics Supplement No.* 3. *Pp. vi* + 218. *The Institute of Physics, London.* 1954. 35*s. net.*

Introduction to Atomic and Nuclear Physics (*third edition*), *by Henry Semat. Pp. xii* + 561. *Chapman and Hall Limited, London.* 1954. 50*s. net.*

TECHNOLOGY

Fiberglas Reinforced Plastics, *by R. H. Sonneborn. Pp. xii* + 244. *Reinhold Publishing Corporation, New York; Chapman and Hall Limited, London.* 1954. 36*s. net.*

Successful Commercial Chemical Development, *edited by H. M. Corley. Pp. xxv* + 374. *John Wiley and Sons Inc., New York; Chapman and Hall Limited, London.* 1954. 62*s. net.*

ZOOLOGY

The Evolution of an Insect Society, *by D. Wragge Morley. Pp.* 215. *George Allen and Unwin Limited, London.* 1954. 18*s. net.*

# Notes on contributors

SIR JOHN COCKCROFT,
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Was born at Todmorden, Yorkshire, in 1897 and was educated at Todmorden Secondary School, Manchester University, and St John's College, Cambridge. After serving in the Royal Artillery in the first world war he studied electrical engineering at the Manchester College of Technology, and afterwards went to Cambridge to take the Mathematical Tripos in 1924. After working with P. Kapitza on the production of strong magnetic fields and low temperatures, he collaborated with E. T. S. Walton on the disintegration of nuclei. From 1935 he took charge of the Royal Society Mond Laboratory at Cambridge and directed its research on low temperatures. He was university lecturer in physics, a Fellow of St John's College, and, in 1939, Jacksonian Professor of Natural Philosophy. During the war he worked on radar as Chief Superintendent of the Air Defence Research and Development Establishment. In 1940 he took part in early considerations of the feasibility of atomic bombs and atomic piles. In 1944 he accepted the directorship of the Montreal Laboratory of the National Research Council of Canada, and became Director of the Chalk River Laboratories. In 1946 he returned to England to become Director of the Atomic Energy Research Establishment, Harwell.

T. G. PICKAVANCE,
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Was born in 1915 and was educated at Cowley School, St Helens, and the University of Liverpool. Between 1937 and 1939 he took part in work on the construction of the Liverpool cyclotron, and was also engaged in studies of cosmic radiation. Shortly after the outbreak of the last war he joined the team formed at Liverpool for work on the atomic energy project. He continued this work, serving also as lecturer in physics, until 1946, when he joined the staff of the Atomic Energy Research Establishment at Harwell as the leader of a team responsible for the construction and use in research of the 110-inch synchrocyclotron. In 1954 he took charge of a new group, with responsibility for the next phase of the high-energy accelerator programme at Harwell.

J. M. BIJVOET,
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Was born in Amsterdam in 1892 and studied chemistry at the Municipal University of Amsterdam, where in 1929 he was appointed lecturer in crystallography and thermodynamics. In 1939 he took up his present post of professor of physical chemistry at the University of Utrecht. His research has been mainly in the field of X-ray analysis, ranging from the subject of his thesis—the crystal structure of lithium and lithium hydride—to the structure determination of strychnine and, more recently, to the determination of absolute configuration. He has established in Holland a school of X-ray crystallographers. In collaboration with the late Dr Kolkmeyer and Professor MacGillavry he has published an introductory textbook on X-ray analysis. Is section editor of 'Structure Reports', issued by the International Union of Crystallography, of which he was President in 1951–4. He is a member of the Academy of the Netherlands and a foreign member of the Flemish Academy and the Academy of Uppsala.

WILLIAM HOLMES,
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Was born in 1917 and was educated at Manchester Grammar School and Magdalen College, Oxford. Is now a University Lecturer in Zoology and Comparative Anatomy at Oxford, and a Fellow and Tutor of St John's College. Much of his research has been on the histology of the nervous system.

E. GLUECKAUF,
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Was born in 1906 and studied chemistry at the University and at the *Technische Hochschule*, Berlin. Subsequently he did research in the laboratory of F. A. Paneth, first at Imperial College, London, and then at Durham. He was a Mackinnon Research Student of the Royal Society from 1942 to 1944. In 1947 he joined the Atomic Energy Research Establishment at Harwell, where he built up a large physical chemistry group. His main contributions to chemistry are scientific papers on the theory of chromatography and ion exchange, on micro-constituents of the atmosphere, and on specialized fields of radioactivity. He is now a Deputy Chief Scientific Officer at Harwell, in charge of fission product technology.

DEREK J. PRICE,
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Was born in 1922 and studied experimental physics at the University of London. During the last war was engaged in research on the optical properties of metals at high temperatures. After periods as Commonwealth Fund Fellow in mathematical physics at Princeton University and lecturer in the University of Malaya, he was awarded an Imperial Chemical Industries Fellowship at Cambridge University, for the study of the history of scientific instruments. He is now continuing this work at Christ's College, Cambridge, with the help of the Nuffield Foundation. Is author of 'The Equatorie of the Planetis,' an edition of an astronomical manuscript thought to be a holograph work by Geoffrey Chaucer. Is at present preparing a catalogue of antique scientific instruments in the British Museum and an international check-list of astrolabes. Is a curator of the Whipple Museum, Cambridge.

SIR FRANCIS KNOWLES,
*M.A., D.Phil.,*

Was born in Ottawa in 1915 and was educated at Radley and at Oriel College, Oxford, where he specialized in zoology and comparative anatomy. In 1937 he held the Oxford University Naples Scholarship and studied the endocrinology of lampreys and crustaceans at the *Stazione Zoologica*, Naples. There he began studies on neurosecretion which were interrupted by the war, but which he was afterwards able to recommence in Bermuda, aided by a grant from the Royal Society. He at present holds a grant from the Nuffield Foundation to carry out a programme of research on neurosecretion in crustaceans. He is interested in the training of biologists and has been in charge of the biology department of Marlborough College since 1938. He has published a number of elementary textbooks of biology.

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